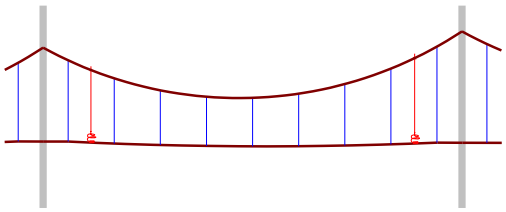
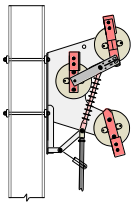
Sydney's Heavy-Rail Overhead Wiring System

Written by
Ken FitzGerald



1. Conductors



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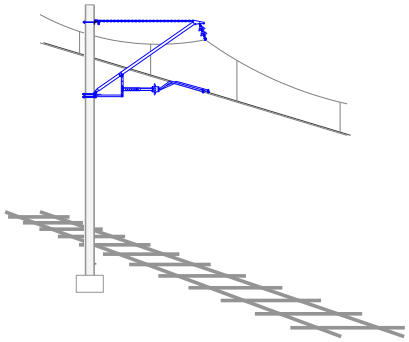

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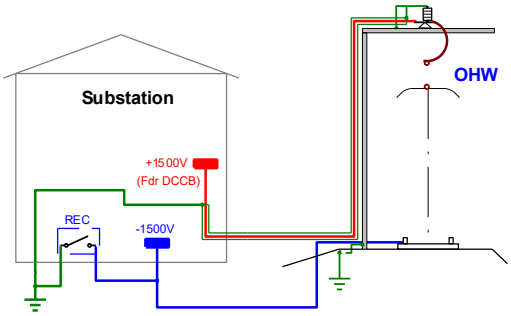

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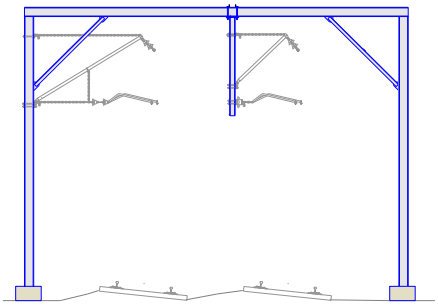

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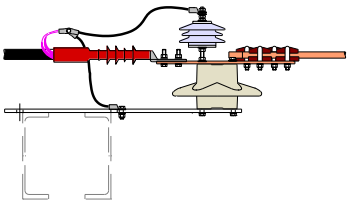

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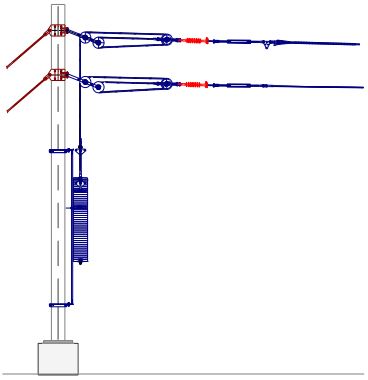

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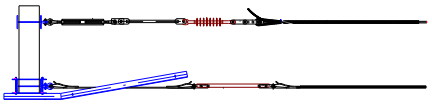
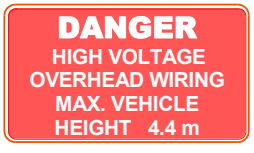
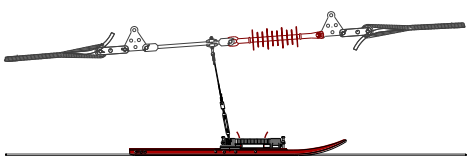


10. Over-Run Protection

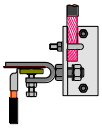
5. Overlaps



11. Signs



6. Section Insulators



12. (Bonding)

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Sydney's Heavy-Rail
Overhead Wiring System

Written by Ken FitzGerald B.E., M.Eng.Sc. (Electrical, UNSW)

June, 2022

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Figure 2 - Simple OHW for single track (Dapto to Kiama)

Figure 3 - OHW supported by Tunnel Cantilevers at Chatswood Station

Figure 4 - OHW installed near Epping Station c. 2010

1 Introduction

1.1 About This Document

My aim in writing this document is to help the reader to develop an understanding of the *character* of Sydney's 1500 volt dc *heavy rail* electric traction overhead wiring (OHW) system.

The document is intended primarily for design engineers who may be new to this field, since there's been quite an influx of engineers in recent years. This is likely a consequence of the essential role the railways play in Sydney's transport network, and particularly as passenger numbers seem to be growing exponentially over the past decade or so, which is a good thing for many reasons. The information contained in this document may also be of use to construction and maintenance engineers, and possibly others who may have an interest in this topic. I have endeavoured to keep the contents relatively simple, but there are more detailed descriptions where needed.

(Note that it does not deal with the 750 volt *Light Rail* systems that have made a recent comeback to Sydney. Nor does it venture into the OHW for the new 1500 volt dc *Metro* systems currently under construction, although it seems that the OHW equipment located outside the various tunnels has been adapted from, and is similar to, the heavy rail OHW system described here.)

This document describes the most common OHW equipment and components, along with important design concepts that can give an idea of the likely reasoning behind what was built.

It covers equipment types that have been used in the past, but more importantly, it focuses on equipment currently being used in design and construction works, and on equipment that needs to be operated and maintained into the future.

It does not attempt to describe all the various types of OHW equipment ever installed in the electrified network, for to do so would be impractical. However, it does include the vast majority of equipment, and identifies where the most maintenance effort is currently focused.

In 1992-93, as part of the *Technical Maintenance Plan* (TMP) that was under development at the time, most of the variety of existing OHW equipment was identified throughout the electrified network. A *Failure Modes, Effects & Criticality Analysis* (FMECA) process was carried out on all this equipment and related components. This process has provided a substantial base of information regarding what OHW equipment existed and its characteristics in terms of likely failure modes, criticality to the OHW system, consequent maintenance needs, current problems, etc.

This document has drawn heavily from the knowledge gained from the TMP process.

The TMP work required that an equipment classification *structure* be devised to suit Sydney's OHW system. The resulting 12 main functional *categories* that were established are shown on the front cover of this document, and are briefly introduced in *Chapter 2* and explained in much more detail in *Chapter 3*.

Once this TMP work was under way, it made sense that we used this same equipment structure when writing the inaugural official standard – "OHW Standards for the Electrification of New Routes" (then nominated as EP-000801-**ST**), back in 1993. Using this structure helped ensure most of the important aspects were captured in this new standard, which dealt with the fundamental requirements for any new OHW (and it applied also to many aspects of existing OHW).

Under the above 12 categories, in *Chapter 3*, *OHW Equipment & Components,* each piece of OHW equipment is given a basic description, along with its functions, ratings, TMP code, relevant drawings, types, and current policies (whether the equipment is still used, or withdrawn from service, etc.). Where appropriate, photographs or drawings have been included to better describe the equipment or components, along with their functionality.

This is the first update to the original document I wrote and issued in December 1994, which was titled *"*SRA Overhead Wiring Equipment*"*. During the period since 1980 when I started work with the NSW Railways, the organisation had undergone several name changes: *Public Transport Commission of NSW*, changed to *State Rail Authority of NSW*, then to *Rail Services Australia*, to *Rail Infrastructure*, to *RailCorp*, and finally to *Sydney Trains* in 2013 (and who knows what the future holds?).

The title of this original document has now changed to reference specifically the "Heavy Rail" OHW system, as distinct from various "Light Rail / Tram-Line" OHW systems which are once more growing in popularity and prevalence throughout Sydney. As well, the term *Equipment* has been replaced by *System*, since the scope of the document now delves a little into more than just the OHW equipment.

It's almost 30 years since the release of the original document, and in that time, there's been a considerable range of new OHW equipment appear in the network, along with a sizeable effort in design improvements to existing equipment types. It has also witnessed the replacement of vast amounts of "old" OHW equipment built in the early days of electrification (post 1920s), to new (modern) equipment mostly following the current "OHW Standards for the Electrification of New Routes" (document EP-08000001-SP).

The extent of the Electrified Network has also increased substantially over the same period, and all new OHW is designed and built to the above standard.

Also, over that 30 year period, the railway Electrical Design Office had developed many CAD cells for use in OHW designs, and so where possible, I have drawn (so to speak) from some of these cells to help explain various equipment with a little more accuracy than in my previous document. These have been supplemented where needed with photos I've taken during the numerous weekend closedowns attended, along with a few photos taken by others mostly within the organisation, gathered over time. There are also many more diagrams drawn to help explain various situations. After all, "a picture's worth a thousand words".

Speaking of photographs, I've included many that were taken during and after the construction of the ***single-track*** *Dapto to Kiama Electrification Project* (completed circa 2002). There aren't many places that have just the single track in Sydney's OHW network, but I think seeing the OHW equipment needed to service a lone track makes it easier to focus on and comprehend what's being explained in the surrounding text.

As with the original document, I've tried to keep the descriptions in this text simple. And I've included very few equations, by showing only the ones that add meaning to the big picture.

This document has grown substantially in size, with about 1,000 pages and more than 700 diagrams and photos. So, it has been optimised for *viewing on a screen* as a "pdf" file, since it's likely too big and impractical (and costly) to print. The benefits to this pdf format are:

- It can be distributed electronically.
- It can be viewed directly, from desktop computer / laptop / tablet / mobile phone. This heads towards the so-called "paperless office". And after closing the document, with some pdf viewers it can be opened later on to the page that was last viewed – very handy.
- Headings and all subheadings are tagged as *bookmarks*, which can be viewed as a structured index in pdf viewers – they provide quick access to the relevant part in the

document. As well, all referenced *sections*, *figures*, *tables* and *equations* within the document (in brown-red italics) are actually *hyperlinks* that, when clicked on, can take you directly to the part of the document that's referenced (and with some pdf viewers you can also return back to where you were in the document – also a handy feature).

- There's the ability to conveniently *search* for key words (which can be really useful in such a large document). Most pdf viewers include the "*ctrl f*" key combination (or similar) to *find* key words in the document.
- The *zoom in* feature can be useful to see more of the detail, especially in some of the diagrams. Many of the diagrams were produced on CAD and the resolution remains good even when zoomed in closely to see the detail.
- Although *not recommended*, it can be printed and bound if required (although it would be a huge document). Or, more practically, it could be made into in 2 or 3 volumes, e.g. Vol 1: Chapters 1-2, Vol 2: Chapter 3 (the big one), and Vol 3: Chapters 4-12. To cut down on the thickness, it can be printed back-to-back on A4 paper. Also I've tried to keep the size of text and diagrams reasonably large so that it can be printed as the smaller A5 size document (e.g. 1,000 pages can come from 250 × A4 pages then cut in half to A5 size and bound in some manner).
  Note: Many printers these days allow the printing of 4 pages per physical page with appropriate printer/settings (2 pages on each side), with A4 paper giving a 70% smaller (= A5 size) document and cutting down its overall volume. However, to do this, the pages need to be cut in half. Binding the document as a single unit would be almost impossible, so 3 volumes (as described above) would be more practical.

In this update I have also:

- Included some OHW design concepts, as these seem to crop up from time to time, whenever OHW equipment is discussed (and the concepts are often not well understood).
- Included references to applicable standards that may provide further information.
- Made reference to a number of computer programs that can help during design, or may aid understanding various aspects of OHW in a more practical way.
- Inserted a *Glossary of OHW & Related Terms* (in *Chapter 9*) that can help the reader to understand the meaning of an OHW term or concept, or that can point to an area that provides more information, such as a chapter in this document, or a standard, etc.

For those who are not familiar with metric and imperial conversions, refer to *Section 8.4*, *Relevant Unit Conversions*.

A final perusal of this document seems to indicate to me that there's a fair bit of repetition of some important concepts mentioned at various places within the text. In such a large document I've found it probably better to say some important things a few times throughout the document; otherwise, it would have required many more cross references, and may have made it more difficult to read and understand. Anyway, I've already spent well over a thousand hours on this document and so, ultimately, "it is what it is" – see next section.

Lastly, I am open to any ***constructive*** feedback (re-read that word "constructive").
If you see any errors, or if there are areas that could be added, better described or even omitted (for consideration in a possible future update to this document), you can leave a message at the following email address:

kfitzgr@gmail.com

Ken FitzGerald (June, 2022)

1.2 DISCLAIMER

There are a number of observations made by me in this document. They have been based on my 34 years involved in the NSW rail system which, apart from a few years working in substation commissioning, were mostly spent in the OHW discipline, including several years setting new OHW standards. However, my passion was mainly for OHW design work (where most of the more interesting development work was taking place).

Disclaimer:

This unauthorised document has been initially prepared outside work time, and finished off in my retirement over seven years.

It has not been reviewed by anyone, and in such a large document I am likely to make some mistakes.

Also, while great care was taken in the preparation of this document, some observations may be incorrect, especially those before my time, or they may be misinterpreted. And things may have changed recently that I'm not aware of.

No responsibility can be accepted for any inaccuracy or for any adverse consequences arising from the use of the information in this document.

The reader should consult the various current Sydney railway standards available on the Intranet (and also possibly on the Internet), or converse with Standards staff.

Ultimately, ***the Standards must take priority over anything written in this document.***

All care, but no responsibility.

Things change over time. It's highly likely that there have been a number of changes made since my retirement from the organisation in late 2014. For instance, I have heard that the various OHW Standards have been given a totally different reference number to the ones generated in the 1990s when they were initially created. This was likely done recently to bring uniformity with the various other transport authorities under the *integrated transport* approach of *Transport for NSW*. Unfortunately, I wasn't able to update the old numbers for this document (not that they're that old), but I think the *titles* are mostly as they were.

Also, at the time I left, the organisation was embarking on another change to the way engineering assets were maintained, through a process of *Standard Operating Instructions* (as I recall), by using an improved approach to *Condition Monitoring* of the equipment, including the OHW. So, there's nothing here about any changes this may have brought about.

If working in this area, it's crucial to understand the latest situation with regard to Sydney's OHW system, and so it would be prudent to go through the plethora of available Standards for Sydney's rail system. Indeed, any work carried out on the OHW system must be performed to the current versions of these standards.

1.3 ACKNOWLEDGEMENTS

There seems to be a marked absence of documented reasoning behind most things in Sydney's Overhead Wiring system. Countless designs have been produced over the past (almost) 100 years, but there is very little remaining documentation telling of the reasons why certain decisions were made, especially where changes were adopted when some new equipment, process or requirement came along. This lack of documented reasoning is unfortunate, especially for future generations, and particularly because no one likes making the same mistakes again.

However, I must acknowledge the immense contribution made many decades ago by Len Twemlow with his fairly concise hand-written documentation of OHW design theory, which goes back to first principles. In the Design Office we referred to them as "Len Twemlow's Notes", and although they were rather old, they were (and still are) an invaluable guide to OHW design principles and how they related to Sydney's various OHW systems, with particular emphasis on the unusual nature of fixed-anchored OHW.

I should also acknowledge the big influence Phil Smythe has had in helping many to understand the fundamentals of OHW design, along with practical implications. Much has been gleaned from his words of wisdom over my initial years in the railways (whether he knew it or not), and his expert guidance has been very much appreciated.

There are others who have helped me gain a better understanding of the characteristics and idiosyncrasies of Sydney's OHW over the years, and for this I am also very thankful. They include (in no special order): Bob Simpson, John Anderson, Terry Brown, Ian McLellan, Paul Rizzo, David Stuart-Smith, Wilfred Leung, Bob Davies, Greg Hunter, Neal Hook, Tony Jeffs, Louis Petroulias and Subu Nidagal, as well as Paul Honor and Steve Corbin from Civil Design.

I am also grateful to David Hibbert (from the UK) who, in recent years, had provided the encouragement I needed to finally finish this big update to my original document.

Ken FitzGerald – North Sydney OHW Rebuild, 2014 (Photo: Kevin Ng)

Of course, over the decades there have been many other people who have helped me (and others) to achieve a better understanding of the nature of Sydney's OHW system and how it fits in with the Rail system it is serving. *Teamwork* and *professionalism* are terms that readily come to mind which describe some of the human interactions and attributes needed to set important standards, and to complete design and construction works, so that the OHW can be operated and maintained into the future. Many thanks to those unnamed people who have helped in this regard.

Although most of the photos used in this document were taken by me over four decades (I enjoy photography), a few were taken by others within the railways and a few were from outside, and I have acknowledged their contribution when I know the source. And a few others were in the public domain. In all cases, I am extremely grateful for these additional photos and the way they can help to more fully explain the situation in the surrounding text.

Lastly, I would like to thank my wonderful wife, Roslyn, for her kindness and patience, as well as her helpful grammar suggestions and subtle encouragement over the years – "have you finished that document yet?".

1.4 DOCUMENT STRUCTURE

This document has the following main chapter headings:

1. **Introduction**. (This section.) It includes a brief history of the NSW OHW system, and looks at where the OHW system resides within the heavy-rail electric traction network.
2. **OHW Fundamentals**. This offers a *brief* introduction to various terms and the main elements and aspects of the OHW system, in preparation for what follows in Chapter 3.
3. **OHW Equipment & Components**. This is the main focus of the document and is by far the largest section. It contains detailed descriptions of the various types of equipment and common components, and includes some design aspects that may help build an understanding of OHW characteristics (including limitations).
4. **OHW Systems**. This looks at the various different styles of OHW systems installed throughout the electrified network and how the OHW equipment had been applied.
5. **The OHW Environment**. This describes some design, construction, maintenance and operational aspects of OHW, including typical failure modes, reliability and safety issues, etc.
6. **OHW Interfaces**. This section looks at the several surrounding systems that interact with the OHW system, especially the train and the track that it runs on.
7. **OHW Documentation**. A brief view of what design documentation is used to define and describe any new OHW installation (for future reference during its maintenance).
8. **Standards, Equipment Lists & Tools**. These types of documents are used when designing any new OHW, or when altering existing configurations. There are also some conversion factors for those who don't like metric speak.
9. **Glossary of OHW Terms**. This provides a brief description of numerous OHW terms, and makes references to other areas (including Chapters in this document) for more detailed information.
10. **Appendices**. Supplementary information that is referenced from the main document.
11. **List of Tables**. An index to the various tables of information in this document.
12. **Table of Contents**. The structured contents of this document are more fully described here to the full 7 heading levels listed below. (The TOC at the beginning of this document only goes to the highest 3 levels)**.**

Several *heading styles* are used to help understand the various heading levels for navigation through this document. Their hierarchy is listed below (in order of decreasing importance).

1 Heading 1

1.1 Heading 2

1.1.1 Heading 3

1.1.1.1 Heading 4

HEADING 5

Heading 6

Heading 7

1.5 A Brief History of Sydney's Electrification

To begin with, it may be interesting to uncover a little of the early history of how, why and when Sydney developed its electric traction rail system.

For this I refer to a recent document entitled, *Argyle to Waverton Overhead Wiring Upgrade Project – Heritage Impact Statement*, prepared by Conybeare Morrison International for Hyder Consulting / RailCorp in February 2006. This Heritage Impact Statement document was written in support for the (then proposed) work to renew the old OHW across the Sydney Harbour Bridge from Argyle Substation to North Sydney (and Waverton) in 2006. It included what appears to be a good introduction to the history of electrification of the Sydney system, and I summarise and quote some of the salient points below (with page numbers from the original report). It also makes reference to its sources (which I omit here for sake of brevity).

> *[In] "the early 1900s ... the need for a suburban railway system began to be recognised, with gridlock at the approaches of the city centre a common occurrence. In 1908, the first recommendation by the Royal Commission on City Improvements was the immediate introduction of a system of underground electric railway."* (Page 5.)
>
> *"In 1914, [Dr John] Bradfield travelled overseas to study one-span bridges and underground railway design and his resulting report sets the agendas for the spending of the sum of £25 million to 'improve the travel habits of the citizens of Sydney'. As a result, the electrification of the suburban lines received parliamentary approval in 1915 ...".* (Page 9.)
>
> *"Within the Metropolitan area, the existing steam railways are being electrified and a system of new electric railways has been devised to serve the suburbs not yet in railway communication with the City"* (Page 9.)

Sydney's population growth and consequential traffic increases had necessitated improvements to the existing suburban rail system. This was to come about by increasing the size of suburban train cars, and by conversion from steam to electric propulsion.

The proposed wider electric cars required the existing track centres (distance between centres of 2 main tracks) to be widened from 3.39m (11ft 1½in) to 3.66m (12ft), i.e. 270mm more.

Electrification seemed to be primarily driven by the need for the City Underground tunnel system, although there were several other benefits including *"... a faster schedule, more economical operation and greater track capacity"*. (Page 10.)

The enclosed nature of the (proposed) long tunnels did not readily lend themselves to the use of steam trains (or later diesels) because of the huge plumes of smoke generated and lack of adequate ventilation to effectively deal with this pollution problem. The noise and heat would also have been significant issues. Electric trains could readily solve these problems.

Decisions had to be made regarding the options of electrifying the railways using *ac* (alternating current) or *dc* (direct current), and also whether it was to be supplied by *third rail* or by *overhead wiring*. Apparently, Sydney ended up following Melbourne's example and decided on 1,500V dc, using overhead wiring, and it was ultimately based on the British system of the time.

As well as not polluting the immediate environment, electric trains had the advantage of being much quieter and could also rapidly accelerate from start (due to the exceptional torque characteristics of a dc motor at start-up). This quick acceleration is a huge benefit when there are frequent stops involved in the train service, by helping to reduce overall travel time.

The conversion from the normal ac electricity supply to dc for powering the trains was best achieved inside purpose-built substations located beside the tracks, rather than on-board the trains themselves, which would have been virtually impractical with the early technology.

Initially the ac-to-dc conversion required the step-down transformers feeding into *rotary converters* (see *Figure 5*) – large ac motors driving dc generators, providing the 1500V dc at currents (I'm guessing) up to a thousand amps or so. (Later on, the voltage was transformed down and rectified from ac to dc used mercury arc rectifiers and eventually silicon diode rectifiers, which has been current practice for more than 50 years).

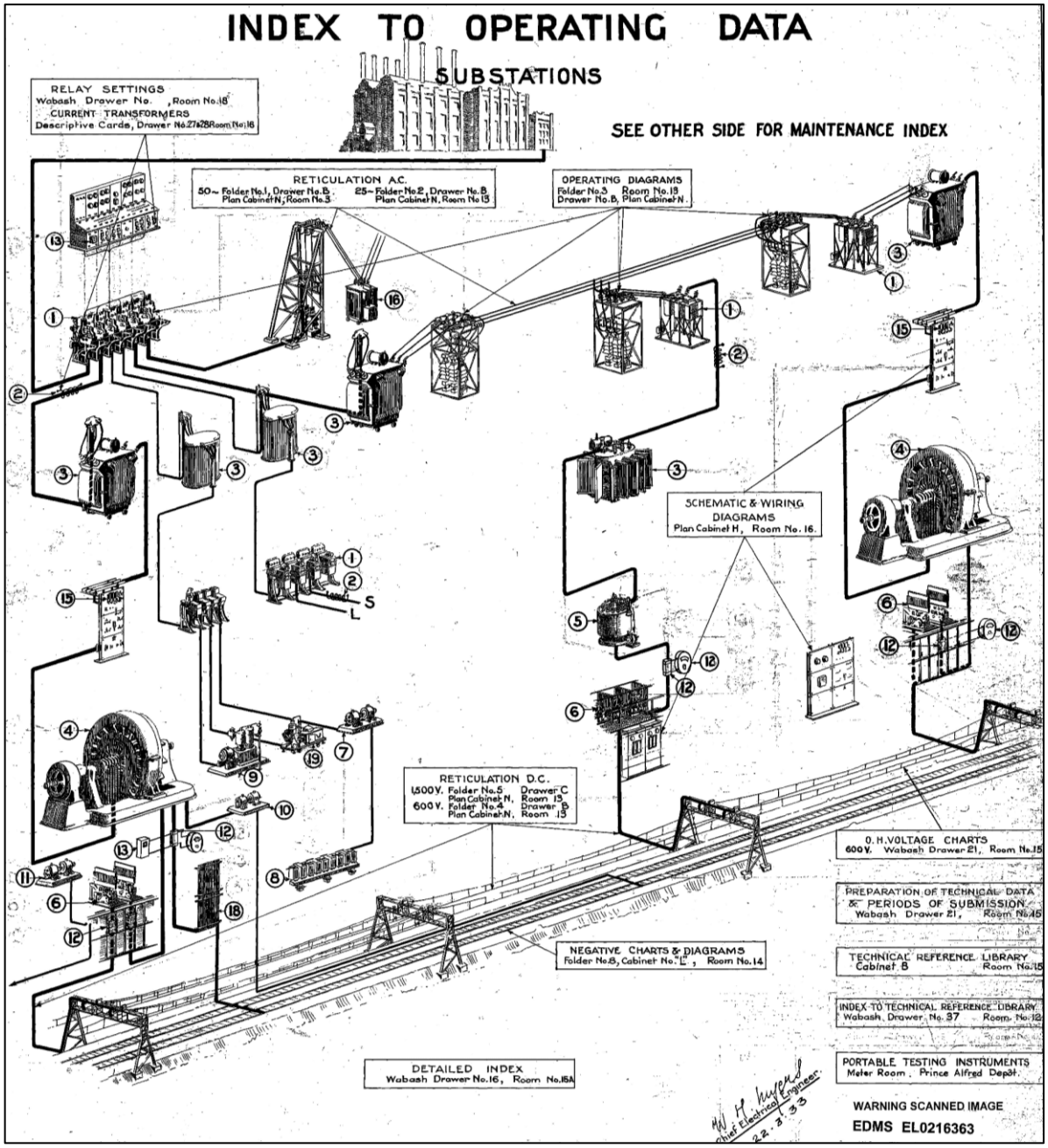

INDEX TO OPERATING DATA
SUBSTATIONS
SEE OTHER SIDE FOR MAINTENANCE INDEX
RELAY SETTINGS
Wabash Drawer No. , Room No.18
CURRENT TRANSFORMERS
Descriptive Cards, Drawer No.27&28 Room No.18
RETICULATION A.C.
50~ Folder No.1, Drawer No.B, Plan Cabinet N, Room No.3
25~ Folder No.2, Drawer No.B, Plan Cabinet N, Room No.13
OPERATING DIAGRAMS
Folder No.3 Room No.13
Drawer No.B, Plan Cabinet N.
SCHEMATIC & WIRING DIAGRAMS
Plan Cabinet H, Room No. 16.
RETICULATION D.C.
1500V. Folder No.5 Drawer C
Plan Cabinet N, Room 13
600V. Folder No.4 Drawer B
Plan Cabinet N, Room 13
O.H.VOLTAGE CHARTS
600V. Wabash Drawer 21, Room No.15
PREPARATION OF TECHNICAL DATA & PERIODS OF SUBMISSION
Wabash Drawer 21, Room No.15
NEGATIVE CHARTS & DIAGRAMS
Folder No.8, Cabinet No. L , Room No.14
TECHNICAL REFERENCE LIBRARY
Cabinet B Room No.15
INDEX TO TECHNICAL REFERENCE LIBRARY
Wabash Drawer No. 37 Room No.12
DETAILED INDEX
Wabash Drawer No.16, Room No.15A
PORTABLE TESTING INSTRUMENTS
Meter Room, Prince Alfred Depot.
WARNING SCANNED IMAGE
EDMS EL0216363

Figure 5 - Old Diagram Showing Substation Conversion Equipment (1933)

The upgrade of the existing railway lines for the electrification required additional height clearances (at bridges, etc.) and better track ballast (to reduce stray dc currents which could otherwise have led to extensive corrosion of services and structures in certain areas).

The first suburban electric train service, *"left Mortdale Car Sidings on Monday 1st March 1926 at 7:10am, running empty to Hurstville and then operating 'all stations' to Sydney. Departing at 7:54am it made its way back to Oatley, at that stage the limit of electric power within the system."* (Ibid., Page 12.)

Also, the first underground railway was just completed from Central Station to St James Station, allowing some trains that had previously terminated at Central to now continue to Museum and St James Stations.

Overhead Wiring was installed on the Sydney Harbour Bridge when it was built in the early 1930s. Trains ran on the west side of the bridge as they currently do. Trams ran on the east side of the bridge; however, this scheme was replaced by car traffic in 1958. Refer to *Figure 6* which shows the OHW support structures for the trams on the left (east) and the trains on the right (west) at Milsons Point (Sydney, as it was, is further south in the distance).

Trains were of the multiple-unit type, consisting of 2 sets of 4-car coupled units, which could be halved for use outside the peak hours.

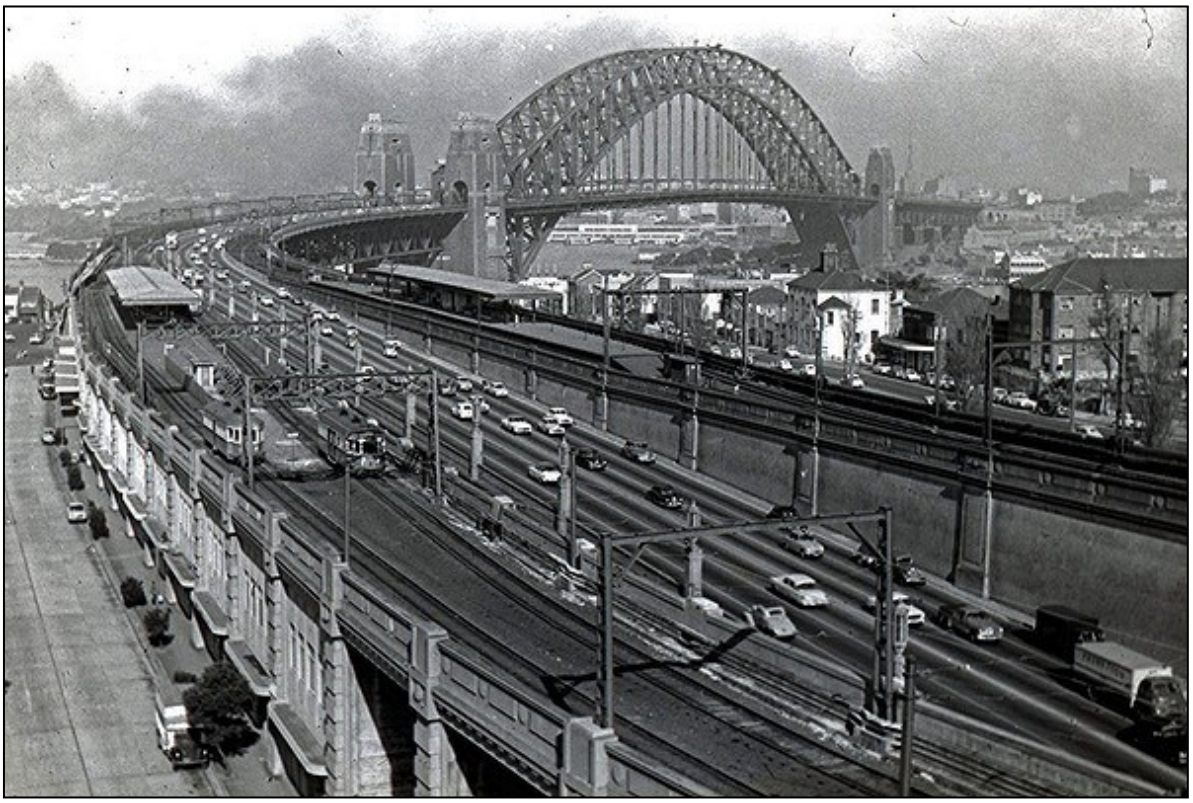


Figure 6 - Early view from Milsons Point of trams (left) & trains (right)

Table 1 below shows an approximate *Electrification Timeline*. This has been based on online information from *Wikipedia* entitled "Railways in Sydney" (with some comments added). This website provides a wealth of information relating to the extent of electrification.

Initially, all passenger electric trains were single deck (as shown in *Figure 7*), but in the mid 1960s Sydney introduced double-deck trains. This configuration allowed many more people to be carried on each train, and they soon became the standard. In 1992 the single-deck *Red Rattlers* (as they were affectionately known) were removed from service, leaving the entire fleet as double-deck trains (excluding the recent *Metro* system).

As I understand it, the introduction of the taller double-deck trains required a significant effort to ensure there was sufficient rolling stock clearance to all surrounding infrastructure, especially inside tunnels and at overline bridges, and also to less obvious items like station awnings. All sorts of structures would have had to be trimmed to allow an unobstructed path, because of the taller outline of the double-deck train.

In the case of OHW, I was told that a special *bell* device was installed on a train and run throughout the network to detect any instances of inadequate contact wire clearances to the top of the train. Apparently, the bell quickly wore out, so there was obviously a huge effort needed to improve OHW clearances as well (by raising contact wire heights, etc.).

However, the huge flow-on benefits of having double-deck train operations over the many subsequent decades has obviously paid off in a huge way.

Year	Location of Electrified Line
1926	Illawarra line to Royal National Park.
	Bankstown line.
	New line – Central to Museum and St James Station.
1927	North Shore line.
1929	Western line to Parramatta.
	Northern line (Strathfield to Hornsby).
	South line to Liverpool.
1931	New line to East Hills.
1932	New line – Central to Town Hall, Wynyard, across Sydney Harbour Bridge, Milsons Point station and North Sydney station.
1936	Carlingford line – Clyde to Rosehill.
1939	New line – Sutherland (Illawarra Line) to Cronulla.
1955	Parramatta to Penrith.
1956	New Line – Circular Quay station opened completing the City Circle.
1957	Penrith to Lithgow.
1959	Rosehill to Carlingford.
	Hornsby to Cowan.
1960	Cowan to Gosford.
1968	Liverpool to Campbelltown
1975	Blacktown to Riverstone.
1979	New twin tunnel line – Eastern Suburbs railway completed to Bondi Junction
1980	Loftus to Waterfall.
1982	Gosford to Wyong.
1984	Wyong to Newcastle.
1985	Waterfall to Port Kembla.
1987	New line opened – East Hills to Glenfield.
1991	Riverstone to Richmond.
1996	Coniston to Dapto.
	New Cumberland line – Campbelltown to Blacktown including Y-link between Harris Park & Merrylands
1998	New line – Flemington and Lidcombe to Olympic Park.
2000	New single tunnel (2 track) line – Central to Sydney Airport to Wolli Creek.
2002	Dapto to Kiama.
2009	New twin tunnel line – Epping to Chatswood.
2015	South West Rail Link – Glenfield to Leppington
2019	New North West Rail Line – Epping to Rouse Hill (Cudgegong Rd)

Table 1 - Approx. NSW Electrification Timeline

Because of the need for large amounts of electricity in the city to power all sorts of equipment, eventually including trains and trams and associated infrastructure (station lighting, etc.), the Railways used to be an electricity generator, with power stations at Ultimo

(commissioned 1899) and White Bay (commissioned 1917). It also had remote power stations at Newcastle (1915) and Lithgow (1928).

However, because of the vast extension of the developing electricity network over the years, in January 1953 this role was transferred to the State Electricity Commission, and the Railways then became a prominent customer.

Figure 7 - A "Red Rattler" Train from a bygone era

The early OHW systems were based on the British systems of that time. All characteristics of the OHW used the imperial measurement system. More of the impact of the British OHW system is described in later chapters.

Australia initiated the conversion over to the metric system in 1970. According to the Wikipedia website titled "Metrication in Australia", it was implemented progressively (over more than a decade), but in 1974 large scale conversion took place in all sorts of industries, including the road transport and electricity sectors, and the building sector changed in 1976.

For the railways, this meant that all future *designs* would be made using the metric system, and all main *references* used for future work (including OHW structure location numbers, standards, etc.) were also progressively metricated. I remember seeing the symbol to the right prominently placed on many of the OHW design drawings at the time, to remind people of the requirement for everyone to embrace and work to the new metric system. For example, specified distances were in millimetres (not centimetres), metres or kilometres, replacing what used to be inches, feet, yards, chains, miles, etc.; mass in kilograms instead of ounces and pounds, etc.

Looking back, I think that metrication was a brilliant move as I find the metric system much easier to work with (but I know older people used to disagree, and probably still do).

I have included some relevant *imperial / metric unit conversions* in *Section 8.4*.

1.6 THE TERM "OVERHEAD WIRING"

It appears that from the early days of Sydney's electrification, the term *Overhead Wiring* – or more specifically *Railways Overhead Wiring* ("ROW") – has always been reserved purely for the 1500V *dc* system of wires that supplied trains, and deliberately did not refer to the system of *ac HV Aerial Lines* (or *Transmission Lines* as they used to be known) that ran mostly beside the tracks and that linked up the various traction substations.

Although nothing seems to be written about this issue, I think this differentiation was needed as it was important to distinguish the unique character of the 1500V dc system, from that of the ac supply to that system (at its various voltages: 33kV and 66kV, and some at 132kV).

The OHW above a track consists of multiple conductors (catenary & contact wires) and with many interconnecting parts. It carries *dc* current, and has enormous *fault levels* (in the thousands of amps). Both of these attributes – ***dc*** and ***high fault level*** – have limited the types of *electrical protection* available (although it may be different with today's technology?).

Also, and importantly, the negative *traction return* path (through the rails of the train tracks) should never be deliberately earthed (except in rare, special circumstances). This is done primarily to minimise any stray dc currents flowing through the earth and finding alternative conductive paths back to the substation, which may corrode any steelwork in these paths.

These aspects all seem to point to the dc traction system requiring a special understanding and treatment. For Sydney, this means reserving the term "Overhead Wiring" for just this system.

I mention this near the start of this document because of its importance. More detail is given in *Section 5.1.2* (after the OHW system has been more fully explained).

Note: The term "heavy current" describes the high-magnitude current (several thousand amps) that is expected to pass through the OHW conductors to supply trains.

1.7 SYDNEY'S HEAVY RAIL "ELECTRIC POWER" SYSTEM

Prefix	Aspect
EP-01	High Voltage AC Switchgear
EP-02	Power Transformers & Regulators
EP-03	Rectification
EP-04	DC Switchgear
EP-05	AC Auxiliary Power Supplies
EP-06	Auxiliary Services
EP-07	Electric Braking
EP-08	**1500V Overhead Wiring**
EP-09	Traction Return
EP-10	Aerial Transmission Lines
EP-11	SCADA
EP-12	Protective Earthing, Bonding & Electrolysis Mitigation
EP-13	Structures
EP-14	Enclosures

Prefix	Aspect
EP-15	Test & Support Equipment
EP-16	Distribution Transformers
EP-17	Low Voltage
EP-18	Signal Air Compressors
EP-19	Fault Protection
EP-20	High Voltage AC & Traction Cables
EP-21	Surge Protection
EP-22	Voltage Transformers & Current Transformers
EP23	Low Voltage Installations (Rail Network Infrastructure)
EP-90	Electrical System Requirements
EP-95	System Safe Operation
EP-97	Distribution Substation
EP-99	System Substation

Table 2 - NSW Railways "Electric Power" Equipment Categories

During the early 1990s, a number of senior Electrical Engineers devised a classification structure that described Sydney's railway electrical traction system for the proposed Technical Maintenance Plan (TMP) that was under development at the time. This was a huge but essential undertaking. The same task was also taking place at that time with the Civil, Track and Signalling disciplines. It formed part of the new Reliability Centred Maintenance (RCM) approach, with the aim to more efficiently and effectively manage and maintain the various assets throughout their life-cycle.

The electrical system was given the name *Electric Power* and used the prefix "EP".

All Electrical Standards were prefixed with "EP", for example Overhead Wiring was designated "EP-08". For more information, the main description of the TMP is given in document EP-00-00-00-00-MP, "Electrical Technical Maintenance Plan".

Table 2 shows the primary structure listing of EP numbers and corresponding categories or aspects of electrical equipment from this initial TMP document (with Overhead Wiring highlighted).

1.7.1 The 1500V OHW Electrified Network

Figure 8 will definitely test your eyesight, but it shows the extent of the heavy rail electrified system of 1500V Overhead Wiring as it was in 2014 (when I retired).

Since then there have been a few significant additions, most notably the new North-West *Metro* Line from Chatswood to beyond Rouse Hill. (The other newer Metro lines, including the one currently being built under Sydney Harbour, won't be covered in this document.) Also, the Carlingford line was removed in about 2020 to make way for a new Light Rail system from Carlingford to Westmead via the streets of Parramatta. (This removes the major level crossing at Parramatta Road, which had been notorious for all sorts of problems – including damage to OHW – as cars competed with trains for transit.)

The main *extent* of the 1500V electrified traction network is/was as follows – from *Sydney*:

a) ***North to Newcastle***. There is approximately 165kms of double track. The electrification to Hornsby was completed in 1928, followed by electrification to Gosford in 1960 and to Newcastle in 1984. Note that the OHW from Wickham to Newcastle was dismantled in 2015 to make way for the replacement light rail service (apparently to allow improved vehicular and pedestrian access at Newcastle). Trains from Sydney now terminate at Newcastle Interchange at Wickham (west of Wickham Station).

b) ***West to Lithgow***. There is approximately 160kms of double track, with some 4 track sections. The electrification to Lithgow was completed in 1957.

c) ***South to Glenlee***. There is approximately 60kms of double track. The electrification to Liverpool was completed in 1928 and to Glenlee in 1968, which was later truncated to Macarthur in the early 2000s. An extension from Glenfield to Leppington was completed in 2015.

d) ***South Coast to Port Kembla and Dapto***. Approximately 107kms of mostly double track. The electrification to Sutherland was completed in 1926, to Waterfall in 1980, to Port Kembla in 1985, to Dapto in 1992 and to Kiama (mostly single track) in 2002.

Aside:

The North West Rail Line was completed in 2019. This *Metro Line* takes over the full extent of the recent Epping to Chatswood Rail Line, which is mostly underground in twin tunnels (completed in 2007). The new line continues in new twin 15km tunnels from Epping to Bella Vista, and a 4km *Skytrain* on viaduct structure from Kellyville to beyond Rouse Hill. Apparently, although not the first area to employ driverless trains in Australia, it is a first for any passenger Metro-style trains here.

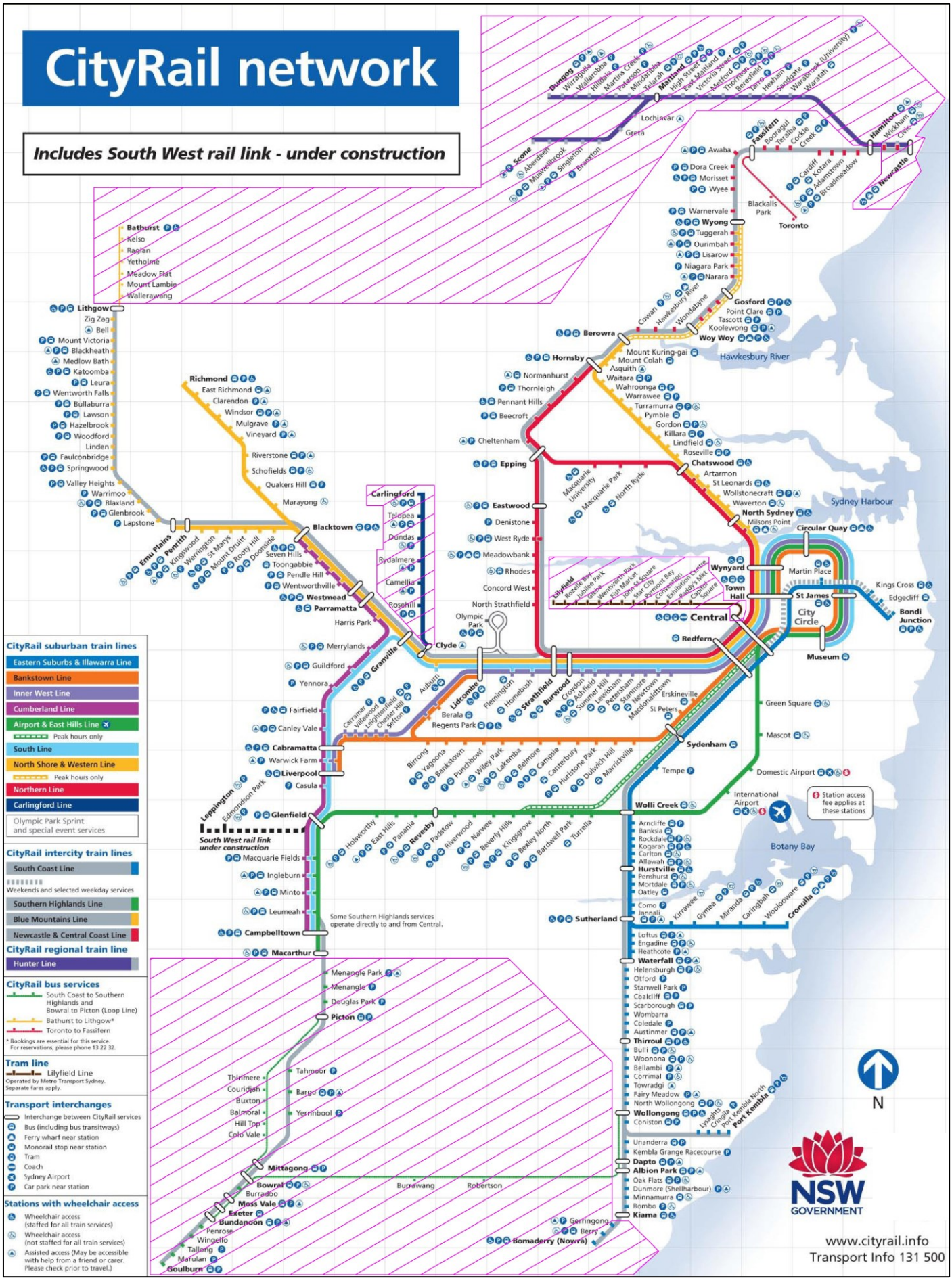

CityRail network
Includes South West rail link - under construction
CityRail suburban train lines
Eastern Suburbs & Illawarra Line
Bankstown Line
Inner West Line
Cumberland Line
Airport & East Hills Line
Peak hours only
South Line
North Shore & Western Line
Peak hours only
Northern Line
Carlingford Line
Olympic Park Sprint and special event services
CityRail intercity train lines
South Coast Line
Weekends and selected weekday services
Southern Highlands Line
Blue Mountains Line
Newcastle & Central Coast Line
CityRail regional train line
Hunter Line
CityRail bus services
South Coast to Southern Highlands and Bowral to Picton (Loop Line)
Bathurst to Lithgow*
Toronto to Fassifern
* Bookings are essential for this service. For reservations, please phone 13 22 32.
Tram line
Lilyfield Line
Operated by Metro Transport Sydney. Separate fares apply.
Transport interchanges
Interchange between CityRail services
Bus (including bus transitways)
Ferry wharf near station
Monorail stop near station
Tram
Coach
Sydney Airport
Car park near station
Stations with wheelchair access
Wheelchair access (staffed for all train services)
Wheelchair access (not staffed for all train services)
Assisted access (May be accessible with help from a friend or carer. Please check prior to travel.)
South West rail link under construction
Some Southern Highlands services operate directly to and from Central.
Station access fee applies at these stations
Sydney Harbour
Botany Bay
Hawkesbury River
N
NSW GOVERNMENT
www.cityrail.info
Transport Info 131 500

Figure 8 - The extent of the NSW "Heavy Rail" Electrified Network (c. 2014)

1.7.2 Substations & Sectioning Huts

Throughout this document I use the abbreviations "S/S" for Substation and "S/H" for Sectioning Hut. (I have used the abbreviation "SS" for stainless steel.)

Figure 9 is a photo showing a substation, built in the early 1980s, with its 2 independent electrical supplies from the *HV ac aerial feeders* (or *transmission lines* as they used to be called). This supply is converted to 1500V dc to ultimately supply the OHW system. In this instance, 1500V *positive feeder cables* go underground and up the OHW masts to feed the OHW (there are 4 electrical sections to be fed). And 1500V *negative cables* feed out to the track itself (for *traction return currents* that complete the electrical circuit).

There were 61 dc substations in the system in 1988 and this has grown to 83 as of early of 2012. There are likely many more substations than this now.

Most of the substations have two transformers and accompanying rectifiers which convert the high ac voltage to a nominal 1500V dc. It is usual practice to have only one transformer and its rectifier operating at a time, with the other on *standby*. The rectifiers of various nominal full load ratings have been used (2.5MW, 4MW and 5MW at 1500V dc). The majority are of 12 pulse configuration and 4 or 5MW rating.

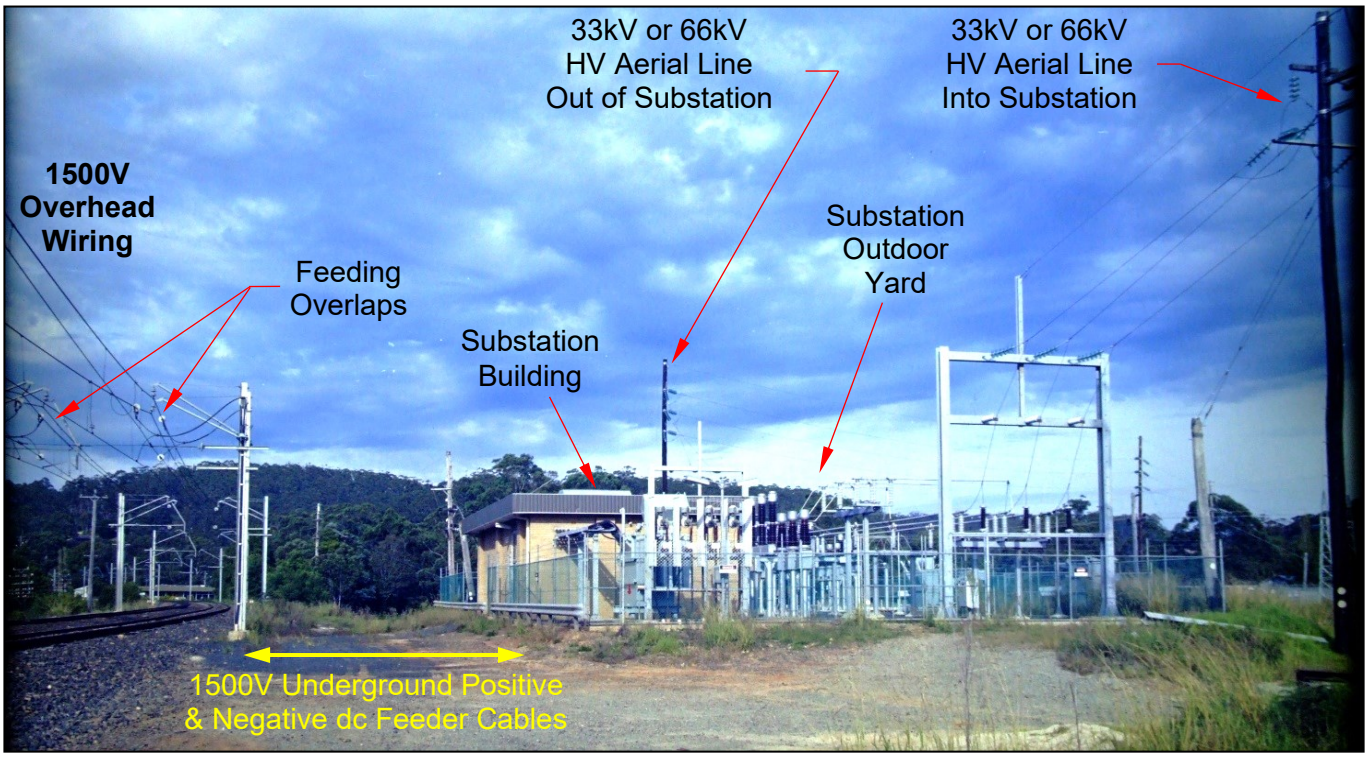


Figure 9 - Typical Electrical Traction System Configuration

Substation spacing varies between 4km (where 3,100 tonne electric freight trains used to operate) to 15km on flat country with predominantly suburban passenger traffic. Spacing is dependent on a number of things, including the energy demanded by the trains, train headways, the OHW configuration, track configuration (number of tracks in parallel), track grades, and even electrolysis effects (due to the resulting voltage on the track).

Usually there is one sectioning hut located about midway between substations. However, west of Penrith they often installed 2 sectioning huts between substations, which had a few benefits including reducing the construction costs of the project at the time (c. 1957).

Sectioning huts enable electrical sectioning and protection of the OHW, and they interconnect the overhead wiring in both directions of the sectioning hut. In cases of 2 or more tracks, a sectioning hut feeding more than one track connects all electrical sections together, which

helps reduce the overall OHW circuit resistance from adjacent substations. This in turn importantly helps to strengthen the supply voltage at a higher level closer to 1,500V, to benefit the nearby trains. This also helps to minimise power loss due to the electrical circuit resistance in the OHW (= ongoing saving $$$).

During recent times, in an attempt to inject more power into the system at certain crucial locations in the network, existing sectioning hut locations have been converted to substations. This action is due mostly to the higher power demands from modern trains, (i.e. trains that demand more *current*), but also there are many more trains on the tracks these days.

As of the end 2011, there were 74 sectioning huts in the electrified network.

More details on this OHW interface can be found in *Section 6.1*, *Substations & Sectioning Huts*. In particular, its accompanying *Figure 661* is a diagram showing a typical configuration of equipment needed for supplying electric power from substations and intermediate sectioning huts, out to the various OHW electrical sections.

1.7.3 High Voltage Supply

The three-phase 50 Hz supply to substations is provided directly from the various electricity supply authorities, at 33kV, 66kV or 132kV. (See diagram in *Figure 661* much further on.)

Sydney's Electric Traction System has its own high voltage (HV) supply network, which has been designed to provide a reliable electrical supply to trains and other associated "essential services" (including the signalling system, station buildings, lifts & escalators, etc.).

The various traction substations are inter-connected using *HV aerial lines*. These used to be called "transmission lines" (TL) up until 2000, but this new term brought us into line with proper industry terminology (with the term *transmission lines* reserved for transmitting power at much higher voltages over longer distances).

These aerial lines are mostly supported from wooden poles and to a lesser extent from steel towers or steel poles. Concrete poles have been avoided over the years due to possible electrolysis corrosion of the necessary steel reinforcing hidden within the concrete, when they're located in an area of possible stray railway dc currents (which can corrode the steel).

The aerial lines most often follow beside the rail corridor, as seen in *Figure 227* further on.

Sometimes underground 11kV, 33kV and 66kV *cables* are also used where aerial lines are not appropriate. Cabling is done mostly for safety reasons (there may be a higher risk of electrocution if people are near exposed aerial conductors). Indeed, the use of underground HV cables has increased over the years, mostly because of the need to get rid of HV aerial lines in built-up areas (which are becoming much more common-place). While they may appear to be desirable, HV cables are generally more expensive to implement, and they do have other disadvantages (e.g. being mostly hidden below ground, they are sometimes accidentally dug up and damaged).

1.7.4 Security of Supply

Almost everything related to the railway's electrical supply system to the trains has some "N+1" redundancy, meaning some backup or standby equipment can take over in case of a failure of the main equipment. This comes from a long-standing policy that deemed the electrical supply to trains as an "essential service". As testament to this, refer back to *Figure 5* which is a diagram, signed by the Chief Electrical Engineer in 1933, showing the early equipment needed for converting HV ac to 1500V dc, and that there are 2 identical sets of such equipment in order to reliably achieve this.

But unfortunately, because the OHW is so closely tied to the track it's supplying, there is very

little opportunity to provide such meaningful redundancy with it. For instance, if a contact wire snaps it will stop trains on that track (even if twin contacts were employed).

These days, the supply includes most major electrical items inside substations (transformers, rectifiers, etc.) and HV feeders between substations. (Refer to *Figure 661* much further on.)

Most of the OHW is also supplied by electric power from substations located at both ends of where any train can be located, in case of power loss from one end (but this configuration has other advantages too).

For a secure supply to be achieved, a substation would be typically supplied from HV feeders in 2 opposite directions, so that a failure of supply to the north, for instance, could result in power being quickly rediverted from the south (or east or west or wherever).

The benefits of this equipment redundancy have been proven many times over the years. It came to the fore in 2008 when an electricity supply problem to Sydney's CBD caused virtually all electrical power to be lost – to businesses, residential apartments and properties, and it particularly affected the road traffic lights, causing major traffic congestion and chaos.

However, train services through the city were unaffected, because the traction HV network has this high degree of interconnectivity from the electricity supply network. Most, if not all, train services (including OHW, signalling and station supplies) remained in service, allowing people to come and go from the city, possibly oblivious to the chaos happening nearby.

Sydney's traction network obtains its power from bulk supply points at some 22 locations scattered across the electrified network. In this approach, HV ac aerial feeders to individual substations can normally be *reconfigured* in a number of ways to get the necessary power to supply trains and associated infrastructure. This also allows for the feeders to be de-energized ("opened") for all sorts of construction and/or maintenance work to be carried out as needed from time to time.

All this supply switching activity is controlled from the Electrical Operating Centre (or its new equivalent).

The various bulk supply points are (or were) documented on HV Diagrams 300 and 301.

1.7.5 The "Mains" Discipline

In the past, the OHW system was *designed*, *constructed* and *maintained* by dedicated *Mains* staff (and I mean "dedicated" in both senses of the word).

In addition to the OHW, these people also looked after the *high voltage ac aerial lines* (transmission lines) and *HV cables*.

So that's three groups – Design, Construction and Maintenance – and each group has their own specialities (knowledge and skills).

Figure 10 shows an old *OHW Staff Badge*, which I understand was worn on the helmet and was used to identify those people with authority to work on the OHW, which was particularly relevant during multi-discipline incident management. (It is no longer used.)

This figure also shows an *OHW Design Badge*, several of which were made to help celebrate the

Figure 10 - OHW Staff badge (left) & OHW Design badge c. 1983 by T.C. Brown (right)

milestones in the electrification designs of the listed rail lines (but also as a bit of fun – a talking point).

These 3 fields – *OHW*, *HV aerial lines* and *HV cables* – require specialist understanding, as there are significant "pitfalls" that could lead to premature failure of equipment, which can ultimately delay trains and take considerable time to locate and affect repair. There are also potential safety issues that may not be well understood by outsiders.

The OHW system is mostly a mechanical system and, as such, is prone to mechanical failures unless it's been well designed, constructed and maintained, and operated within its limits.

All OHW needs to be designed and signed off before it can be constructed. From early days, the designers would normally have a strong electrical background (Electrical Engineers specialising in HV Power), even though the OHW system might be considered mostly a mechanical domain.

Over the past few decades, the way had opened up for Mechanical Engineers or even Civil Engineers to design OHW, and this has some merit. I suspect the reason why Electrical Engineers were used in the past was because of the inherent dangers if the electrical side of the OHW system was not properly understood. This includes how it interacts with other electrical infrastructure, and this can be quite a complex system. It is also essential to have a good understanding of electrical safety issues and their control, as well as the electrical nature of lightning and how to counteract its effects on OHW infrastructure.

Of course, in the past, multi-disciplined Electrical Engineers could do work on the other aspects of the electric traction system apart from OHW: the substations and sectioning huts, electrolysis mitigation, electrical protection, low voltage, SCADA, electrical safety, etc. These are specialist areas for trained electrical personnel only. (Any newcomers would normally be expected to gain some practical experience in these areas, for a better understanding and appreciation of the whole Electrical infrastructure).

Also, in the past, for this *OHW design* approach to work properly, any significant mechanical loading aspects that needed to be checked out were referred to the Civil Design section for their expertise and design work (including the design of OHW Structures). This collaboration has worked well over the many decades.

The main point is, if designers don't have expertise in both the electrical and mechanical domain, then they need to know when they must ask for help/guidance/approvals by referring to engineers from the relevant discipline. And this should work both ways for electrical and mechanical or civil engineers. *Engineering Authority* to the rescue.

2 OHW Fundamentals

This chapter is intended to describe Sydney's OHW system briefly and in relatively simple terms.

It introduces the *OHW Equipment Listing* developed in the 1990s, and serves as a broad introduction to the *categories* of equipment used. Note that *Chapter 3* goes into much more detail and is intended for readers who may wish to find out why things are done the way they are (and why they may have been done differently in the past).

The term *Overhead Wiring* is also called "Catenary System" or "Overhead Line" elsewhere throughout the world, but most of the fundamentals are essentially the same, regardless of the operating voltage.

An Important Note on Scales.

In OHW Design work, it's normal practice to show profile views, of the catenary wire sagging, with a distorted 10:1 vertical scale relative to horizontal scale. Typically the profile view would be drawn at 1:50 Vertically and 1:500 Horizontally.

This vertical exaggeration helps to emphasise what's happening in the more important vertical sense – see *Figure 11* for how this approach compares. (This diagram is actually a copy of that in *Figure 500* much further on in the document.)

The upper view *a)* is what you'd see in the field, whereas the lower view *b)* is magnified 10x vertically, and this should provide a much better understanding of the various parts.

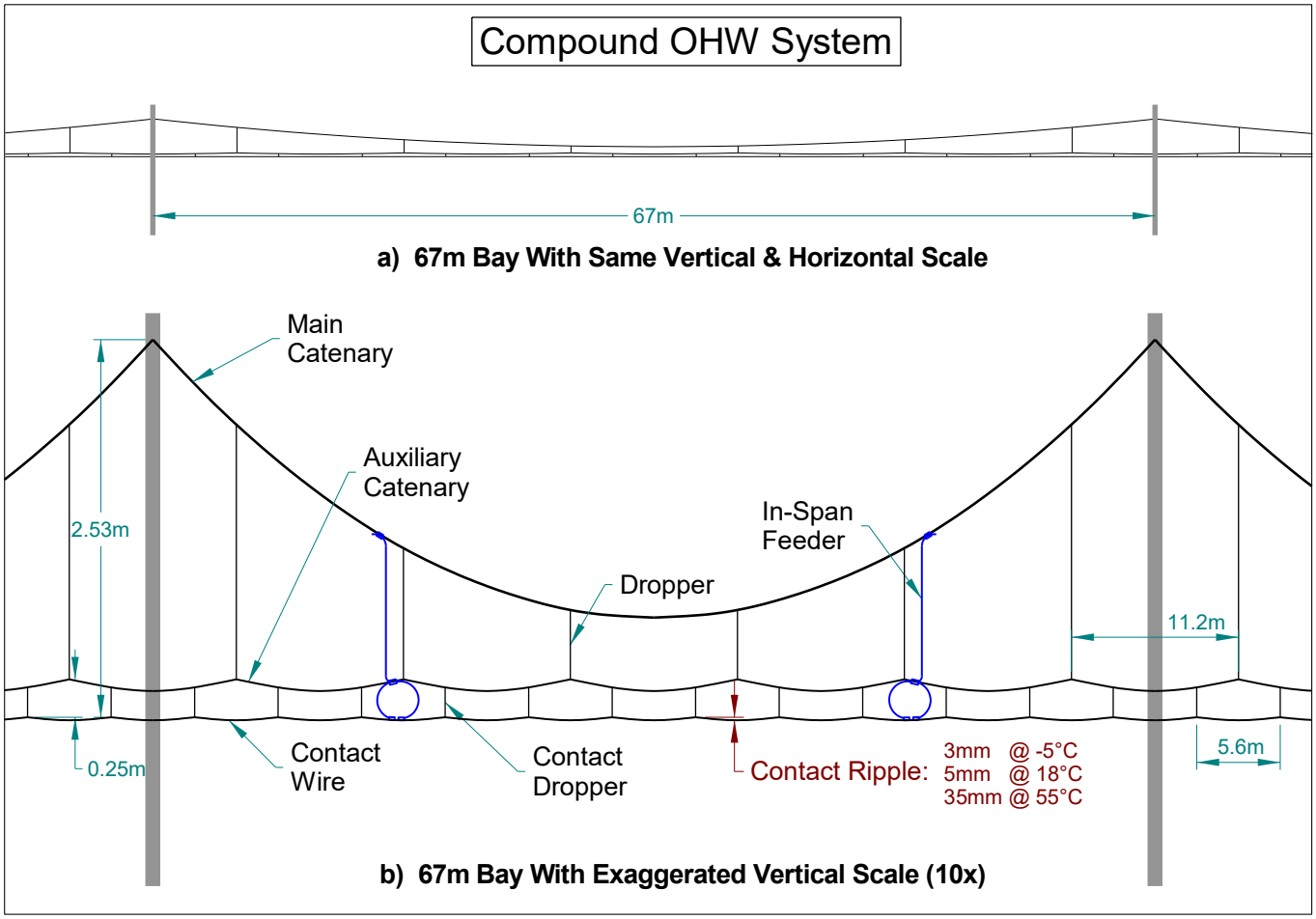


Figure 11 - Example of Actual Side View of OHW (top view) versus Magnified Scale (bottom view)

An example of this approach is given in *Figure 24*.

So, when viewing one of the many profile views of OHW in this document, you need to look for any *10x difference* between vertical & horizontal scales, and if so, understand that the outcome may not be as severe or dramatic as suggested in these particular cases.

Distorted scales are sometimes also used when viewing the OHW relative to track in Plan View, as shown further on in *Figure 61*. The middle diagram has a distorted view to emphasise what's happening in the lateral sense where the action is, whereas the bottom diagram is the same situation but without the distorted scale (it's what you'd see in the field from a helicopter).

Keep it in mind that the 2 principal components in the OHW system are:

- The ***conductors*** (for transferring electrical energy from substations to trains), and
- The ***insulators*** (which allow these conductors to be safely operated at 1500 volts).

2.1 OHW EQUIPMENT LISTING

The equipment list described in this publication has its structure based on the original OHW Technical Maintenance Plan (TMP). This has 11 OHW equipment *categories*. However, I've added a 12th aspect: *Bonding*, which is not really part of the +1500V OHW system, but has been included for the sake of completeness, as it is an area that is often addressed during the OHW design process, and is relevant to Mains staff.

Refer to the listing of the *OHW equipment categories* in *Table 3*.

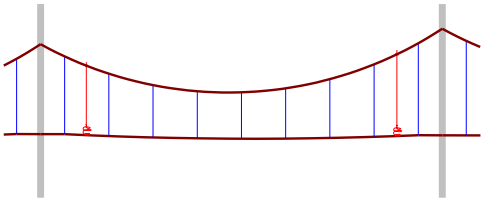
Figure 12 is a simple diagrammatic representation of these equipment categories (and this is repeated on the front cover for ready reference).

Most types of equipment have an associated *TMP Code*, which is intended to reference a set of *Service Schedules*, that dictate the routine maintenance work to be undertaken on the equipment in order to keep it in good operational condition.

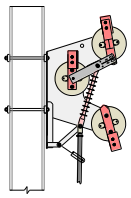
A basic description of the OHW system follows in *Section 2.3*, *OHW Equipment Categories*, but more complete details of the equipment and main components follow further on in *Chapter 3*.

No.	OHW Equipment Category	Description	Examples
1.	**Conductors**	OHW conductors, their configuration and tensioning mode and support elements such as droppers, in-span feeders, etc.	• Regulated – Single Contact OHW • Fixed-anchored – Contact-Only OHW
2.	**Support & Registration**	The equipment that supports or registers OHW conductors	• Liverpool – Glenlee Type 1 Cantilever, • Mark-3 Tunnel Cantilever
3.	**Support Structures**	Type of structure supporting the OHW Support & Registration arrangement	• Wood Pole • Steel Mast • Portal
4.	**Anchors**	Equipment used to terminate and tension the OHW conductors	• Standard Weight Tensioning Arrangement • Gas Tensioning Arrang't • Fixed Anchor Arrangement • Fixed Mid-Point Arrang't
5.	**Overlaps (Airgaps)**	Means of continuing the OHW when one run of OHW is required to end, allowing smooth pantograph passage. Also provides electrical sectioning.	• Feeding Airgaps • Sectionable Overlaps • Non-sectionable Overlaps
6.	**Section Insulators**	Means of providing electrical sectioning of OHW or continuation of OHW with smooth pantograph passage.	• Type 5 SI • Type 6 SI • BICC SI
7.	**Switch Arrangements**	Means of allowing one electrical section of OHW to be energized or isolated from another OHW section.	• 2,000 Amp Switch • 3,000 Amp Switch • Combined Sectioning / Rail-Connecting Switch
8.	**Feeding Arrangements**	Means of electrical connection from supply point to OHW.	• Cable Feeding Arrangement • Aerial Feeding Arrangement
9.	**Surge Arresters**	Means of suppressing electrical surges travelling along OHW.	• General Surge Arrester Arrangement
10.	**Over-Run Protection**	Means of minimising pantograph damage when OHW finishes.	• Skids
11.	**Signs**	To attract attention and convey written information by sight.	• Level Crossing Signs • Switch Identification Signs • OHW Structure Numbering
12.	**(Bonding)**	To provide a current return path to trip the circuit breaker protection in the case of equipment malfunction.	• Spark Gaps on Masts • Bridge Bonding, etc.

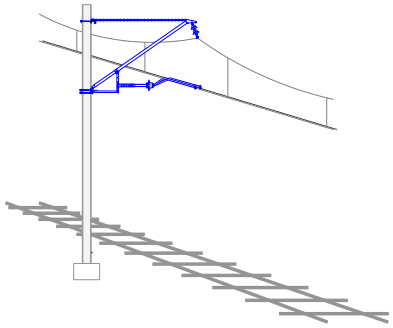
Table 3 - OHW Equipment List



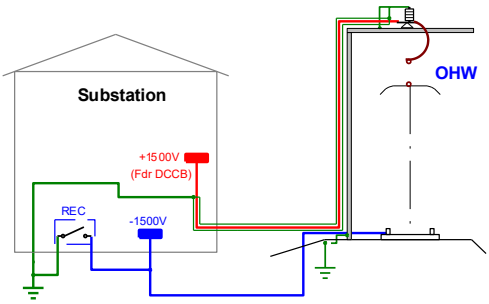
1. Conductors



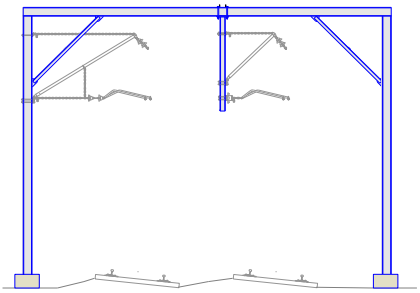
7. Switches



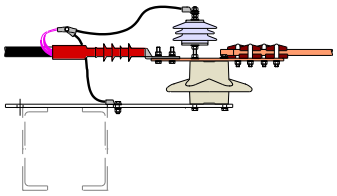
2. Support & Registration



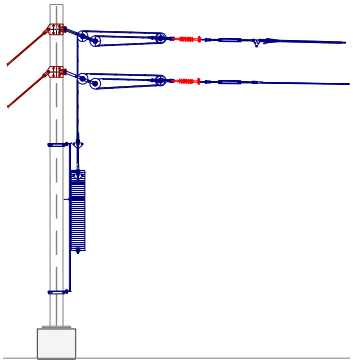
8. Feeding



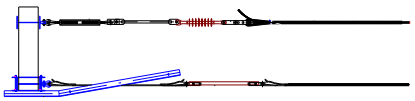
3. Support Structures



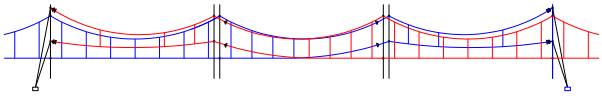
9. Surge Protection



4. Anchors

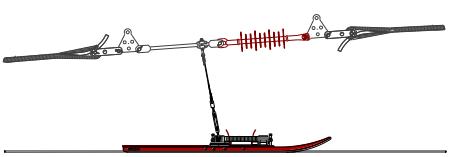


10. Over-Run Protection

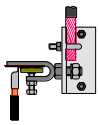


5. Overlaps

11. Signs



6. Section Insulators



12. (Bonding)

Figure 12 - OHW Equipment Categories

2.2 WHAT DOES SYDNEY'S OHW LOOK LIKE?

Figure 13 is a 3-dimensional CAD view of some regulated OHW supported on portal structures around a relatively tight track curve (at Waterfall). This diagram shows and names components of the current preferred OHW system, which is System No. 2 – a regulated tension system with a 270mm² catenary wire supporting twin 137mm² contact wires.

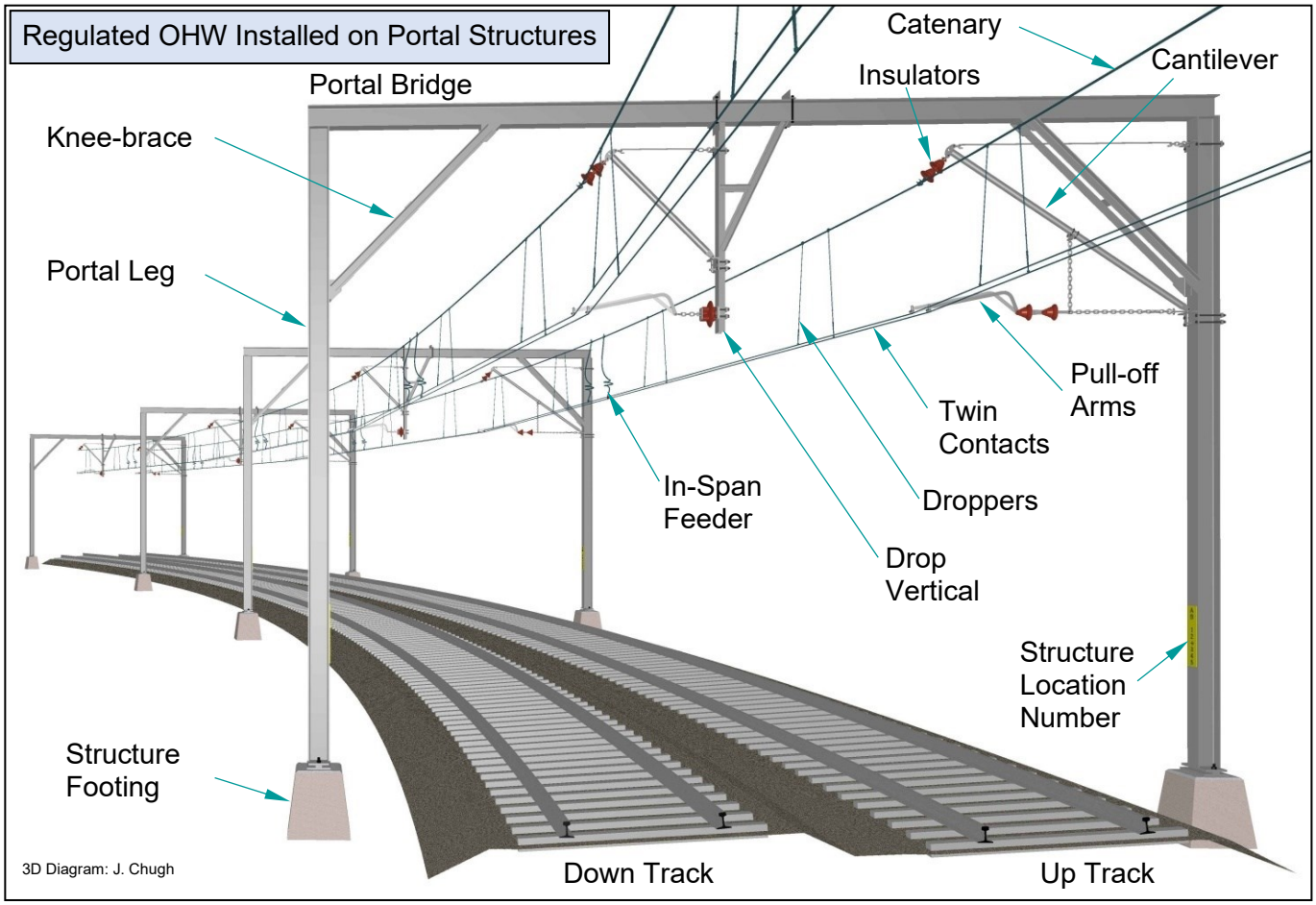


Figure 13 - Typical Components of a recent OHW System

Figure 14, *Figure 15* and *Figure 16* show manually-drawn diagrams developed in the early 1980s, essentially to help train drivers identify and report typical failed OHW components whilst traversing the vast electrified network. The drivers were and are in the best viewing position to communicate early warning of some of the more obvious failures (that may eventually lead to stopping trains if not identified and reported for early rectification). Such failures include fallen branches and all sorts of debris blown into the OHW conductors, vandalism damage, detached droppers or in-span feeders, etc.

Figure 14 shows typical regulated OHW systems, including a standard weight tensioner on the left side and with a gas tensioner (no longer used) on the right side. Regulated OHW systems are preferred these days because of their superior characteristics in dealing with temperature extremes (both hot and cold weather).

Figure 15 shows a typical older fixed-anchored OHW system. These systems are less common these days, but they remain quite suitable for installing inside long tunnels.

Figure 16 shows a different view of some of the main *conductor* and *support & registration* components in a state of failure – these will be described later in *Section 3.1* and *Section 3.2* respectively.

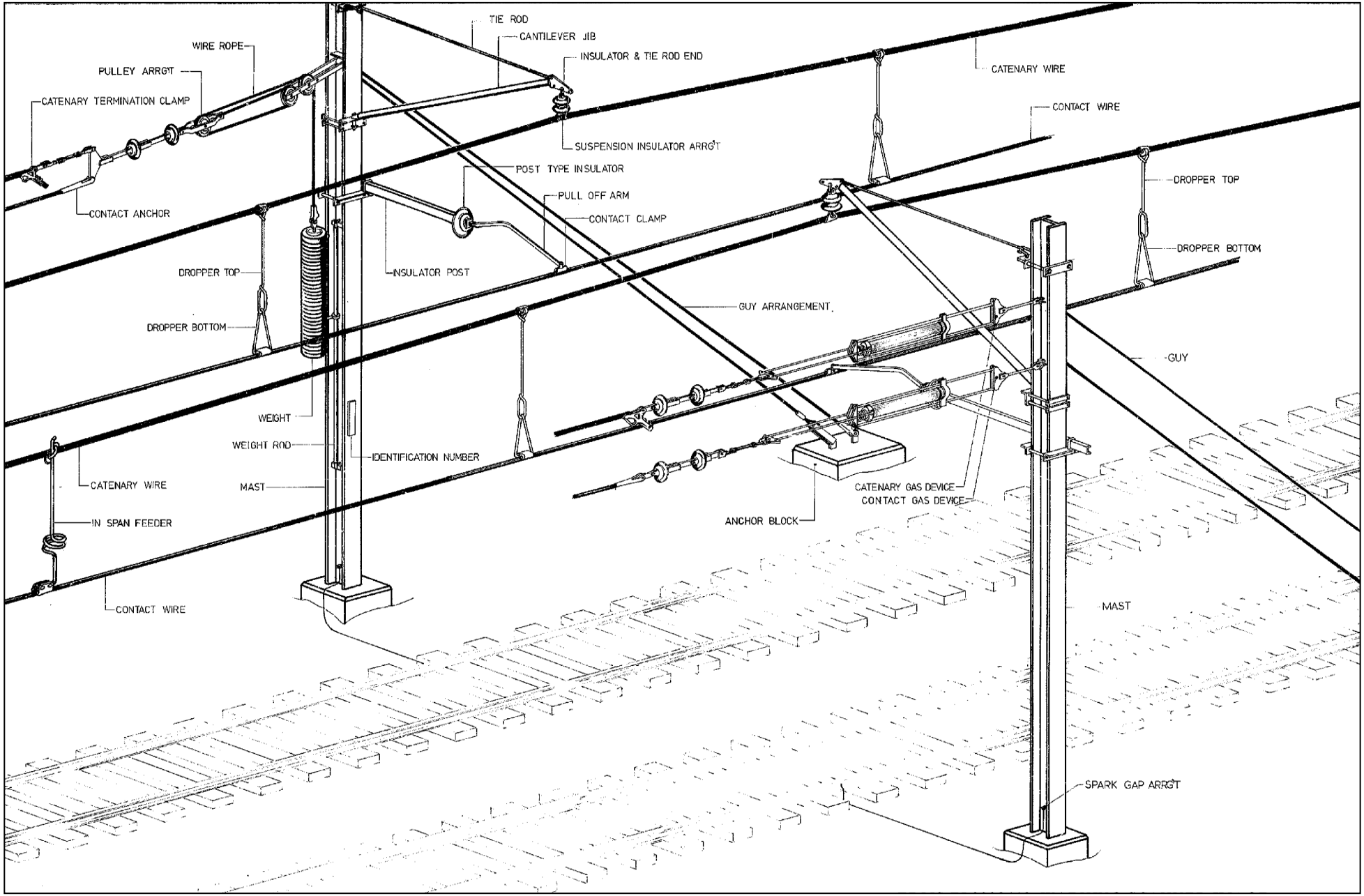


Figure 14 - Typical Components of a Regulated OHW System

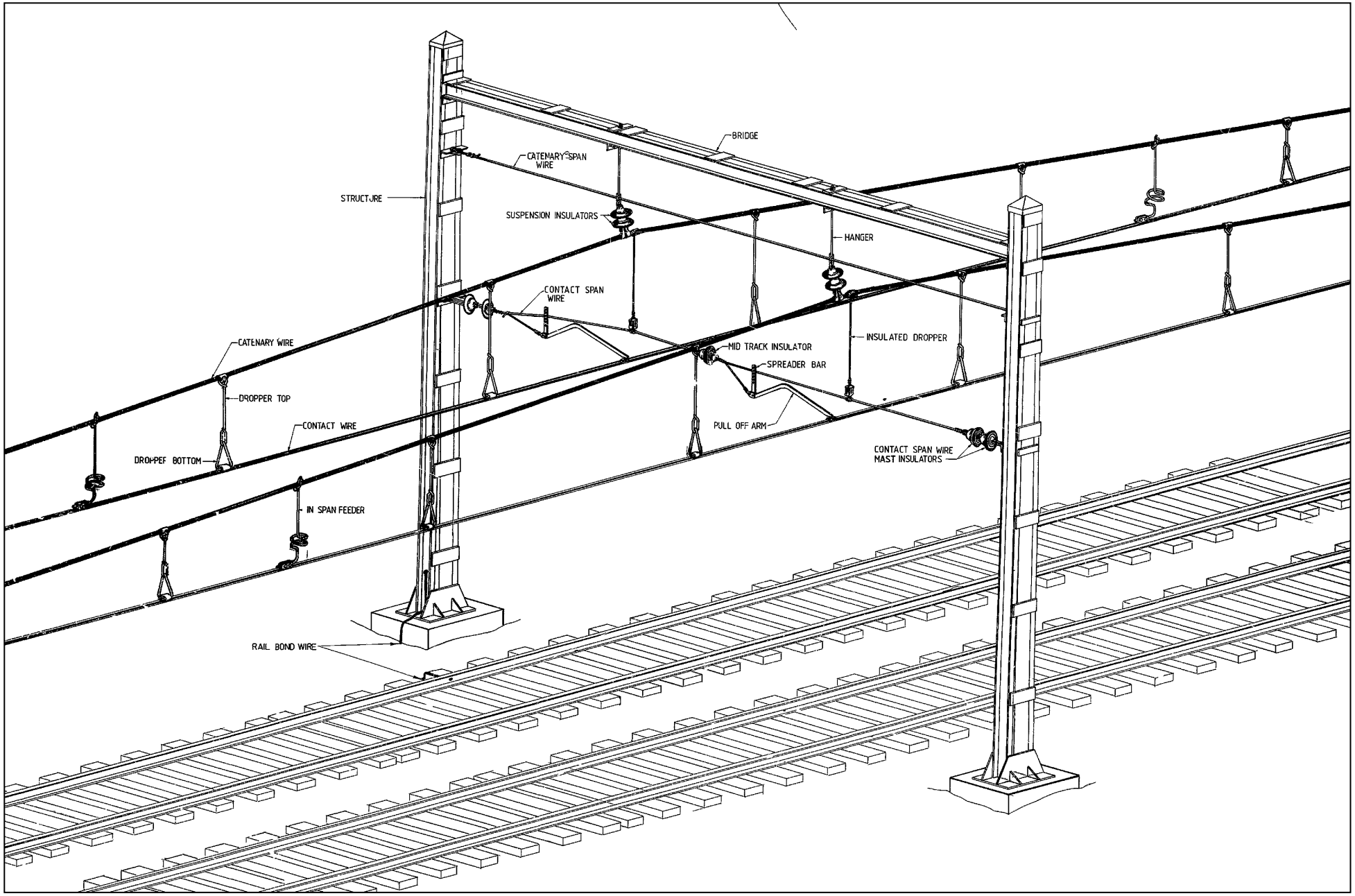


Figure 15 - Typical Components of an old Fixed-Anchored OHW System

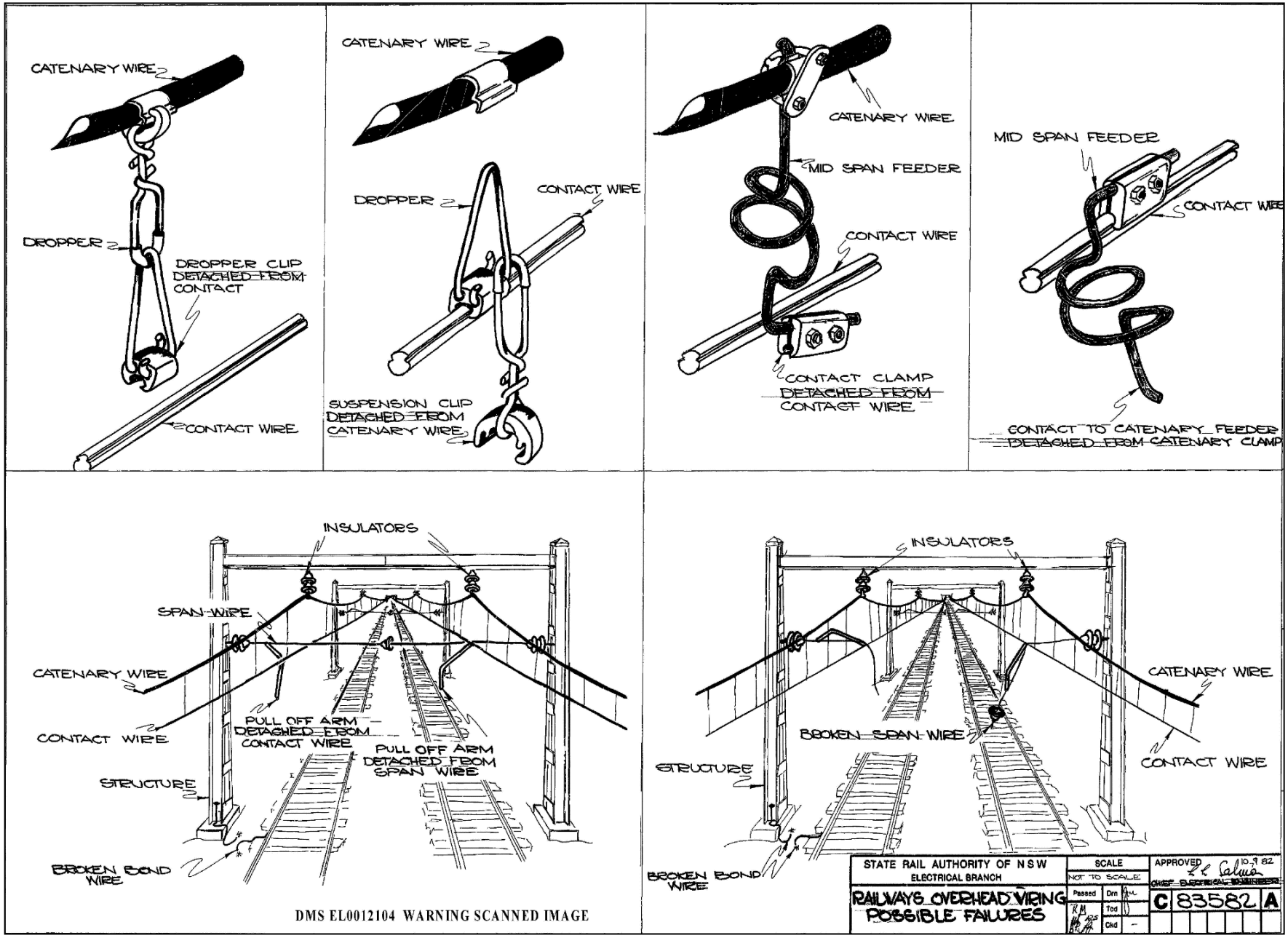


Figure 16 - Old diagram developed to help Train Drivers identify & report on failed OHW Components

2.3 OHW Equipment Categories

This section gives a quick introduction to the 11 equipment categories of Sydney's OHW system, generally following the OHW structure shown in *Table 3*. Also included is a 12th section on *Bonding*.

A more thorough description of all this equipment is provided in *Chapter 3*.

Figure 17 is included here to help give an appreciation of what the first 5 categories of OHW can actually look like for a modern regulated OHW system above a single track (Dapto to Kiama).

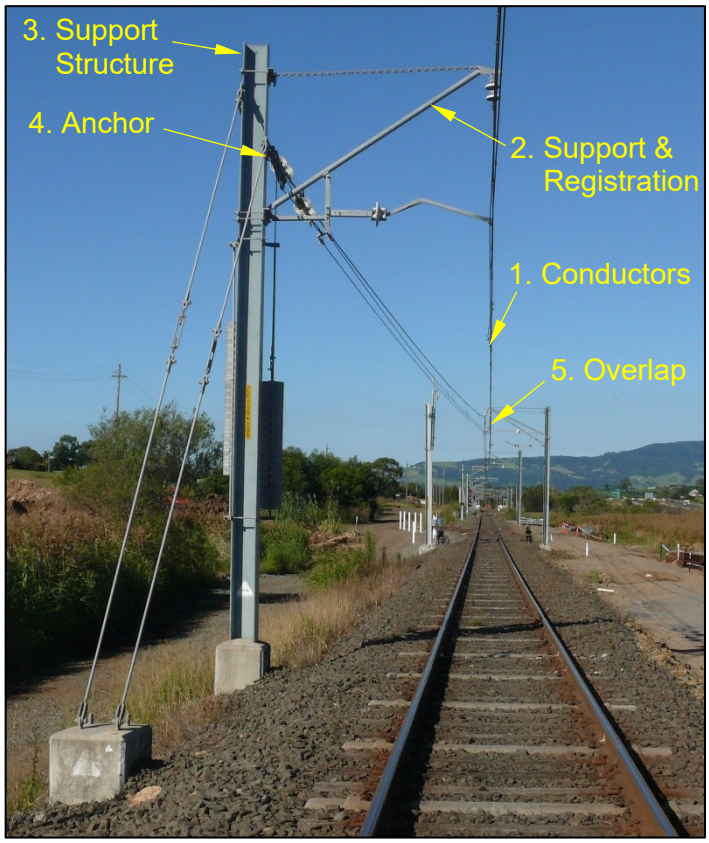


Figure 17 - Some of the Categories of OHW

Note:

Chapter 9 is a *Glossary of OHW & Related Terms*, which can be referred to if unfamiliar terms are introduced but not explained in the surrounding text. It gives a brief explanation and can hopefully guide you to more information within this document or elsewhere.

2.3.1 Conductors

Conductors are wires and associated hardware that are (mostly) located over the track being serviced, so as to supply a train's electrical energy needs.

In its most fundamental form, overhead wiring consists of a *contact* wire (held up and tensioned by some means, and insulated from earth). Normally there is a *catenary* wire located just above the contact wire, to support it and allow it to take on a suitably flat profile for mechanical and electrical interface with a train's several pantographs. Both wires are intended to be precisely positioned above a track (both horizontally and vertically), with the more important contact wire taking its flat or almost flat profile about 5m above track. The sizes of both contact and catenary wires are usually referred to by their respective cross-sectional area in mm² (although it used to be in square inches), e.g. 193mm² (0.3 in²) contact wire.

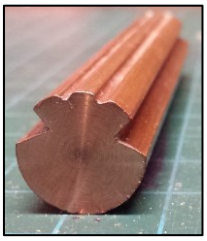
Refer to *Figure 13* for some of the various OHW components in a typical *bay* of OHW. See also *Figure 18* below, which points to the 4 main conductor components:
catenary wire, contact wire, droppers and in-span feeders.

The *contact* wire is the principal component, as it supplies electric current (power) directly to the train's several pantograph collectors. In this situation, a parallel pair of carbon strips on each pantograph pushes upwards, and they slide along the underside of the contact wire, making good electrical contact with it (and resulting in fairly minimal wear over time).

The contact wire is a solid hard-drawn copper wire about 14mm to 17mm in diameter. It has a characteristic large *wedge shape* extruded near its top, and this is designed to allow various clamps to attach to the top of the contact wire while remaining clear of pantographs passing underneath.

Although existing in 3 different copper alloys, Sydney has just 2 standardised contact sizes:

- **137** mm² (which is 13.7mm diameter)
- **193** mm² (16.4mm diameter)

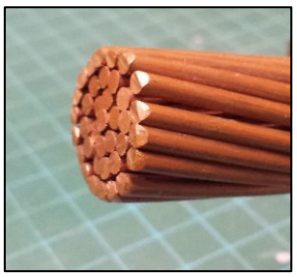


The *catenary* wire is located above the contact wire and takes on a characteristic parabolic shape as this wire sags under gravity. The catenary wire supports the weight of the contact wire, allowing the latter to take on its relatively flat profile. It also helps transmit electric current to and from the contact wire (then to pantograph).

Catenary wires can vary in size from about 16mm to 30mm in diameter, and they are normally made from many small strands of hard-drawn copper wire, which gives it enormous tensile strength.

Standard catenary sizes adopted throughout the electrified network:

- **165** mm² (16.6mm diameter)
- **270** mm² (21.3mm diameter)
- **327** mm² (23.5mm diameter)
- **510** mm² (29.3mm diameter)



Only the 165mm² and 270mm² sizes are preferred these days for new electrification works. Note that a few other sizes were used in the past, and some were made from steel instead of copper. The *Compound OHW System* used across the Blue Mountains includes a third wire located in between catenary and contact wires – the *auxiliary catenary* – and its multi-stranded size is 179mm² in hard-drawn copper, but that's the only place it's been used.

The current rating of the OHW can be improved by increasing the amount of "copper in the air" (total cross-sectional area of all conductors electrically in parallel). This can be achieved by providing additional wires, e.g. installing twin contacts and even twin catenaries, with the second conductor laterally spaced 50 or 150mm on one side or the other of the main conductor. Alternatively, an independent *auxiliary feeder* of the same wire size as the catenary can be added 150mm or so to the side of the catenary.

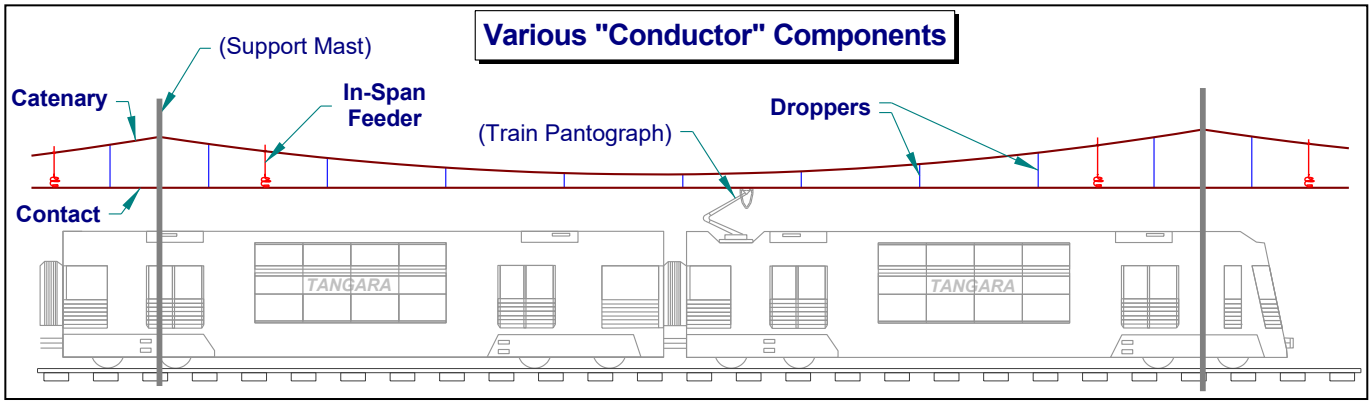


Figure 18 - The four main "Conductor" Components in each OHW Bay

A FEW IMPORTANT TERMS

A ***bay***. The horizontal distance from where the catenary is supported to where it is next supported is referred to as a *bay* (or sometimes *span*) of OHW, and this distance is usually between 20m and 67m these days (or 73m in older OHW systems).

A ***wire run*** – This is the length of OHW conductors (catenary and contact wires) from where they are anchored at one end to where they are again anchored. This distance can vary from as short as 300m (for wiring crossover tracks), and up to about 2 kilometres or even more (for main line runs). The number of bays supporting the wires between anchors can vary, from as few as 3 (when just servicing crossovers), but more typically there are 30 to 60 bays or even more in a run. There are usually a number of reasons for limiting wire run lengths – one basic reason being the amount of wire that can be physically installed onto a large wire drum prior to installation, however, there are other more important reasons (to be explained later).

Droppers – Within each bay, the contact wire must be held up at regular intervals from the catenary wire by vertical droppers. The droppers are typically made from about 5mm or 6mm diameter straightened solid hard-drawn copper wire. They are spaced through the bay at about 4.5 metres to 8 metres apart, depending on the way the OHW conductors are tensioned, i.e. respectively, whether the conductors are under *fixed-anchored* tension (where the tension changes with temperature) or *regulated* tension (which remains relatively constant).

The droppers have individual lengths throughout the bay that cause the contact wire to take on the desired flat or near-flat profile relative to the track below it. In this way, the pantograph can slide along the underside of the contact wire and provide uninterrupted power to the train, even at high train speeds.

In-span feeders – Also within each bay, one or more in-span feeders are installed at regular intervals between the catenary and contact wires (usually there's one in-span feeder in every 30m or so on each contact wire). These feeders are made from flexible multi-stranded 90mm² hard-drawn copper wire. They are required to feed heavy dc current both ways between the catenary and contact wires, and more so as the train draws near and passes by. They are mostly shaped like a spring coil to reduce the likelihood of metal fatigue as the contact wire moves up and down relative to the catenary wire as the uplifted pantographs pass by.

There are a number of other components that are not in every bay, but may be needed here and there as required, including:

- ***Knuckles*** which help to restrain or tie crossing conductors together in some way – catenary to catenary or contact to contact.
- ***Splices*** for mechanically joining catenary wires or contact wires under high tension.
- ***Pennant insulators*** for insulating the catenary and/or contact wires within a run.
- ***Jumpers*** which electrically connect one wire run to another for transferring heavy current, or simply to maintain the same electrical potentials.
- ***Contact wear strips*** which help protect contact wires from further wear in places where pantographs continually rub against the wire, such as above crossover trackwork.

The contact wire must remain on the train's pantographs under conditions of high wind speeds (typically 130km/h). The longer the bay, the more difficult it is to always ensure ***pantograph security*** (which means making sure the contact wire always maintains control of the uplifting pantograph throughout each bay).

Strong winds acting against the side of the tensioned contact wire cause it to deflect sideways – ***blowout***. The greatest horizontal wire deflection occurs at mid bay. A squared law applies to this contact wire blowout – doubling the bay length makes the lateral blowout 4 times as great, which can make it challenging in long bays to keep the contact wire always controlling the uplifting pantograph. Consequently, on straight track the maximum bay length would be limited to about 67m with current OHW designs (resulting in about 350mm blowout).

The ***In-Running*** (IR) contact wire is at a height above track that allows pantographs to run along it. The converse is an ***Out-of-Running*** (OOR) contact wire, which doesn't have pantographs run on it. For example, at an overlap (see *Section 2.3.5*) the in-running contact eventually rises up and goes out-of-running (which is replaced by another in-running contact wire located next to it), then this OOR wire heads off to anchor.

2.3.2 Support & Registration

The OHW catenary and contact wires are supported and held in position above the track by *support & registration* arrangements, shown in **blue colour** in *Figure 19*.

Here, the weight of the wires is *supported* at nominated heights above track, and they are *registered* or held laterally in place at a particular horizontal *stagger* offset from the superelevated (inclined) centre of track. These positions can be seen in *Figure 19*.

The contact stagger is especially important, as this sets the wire position throughout the bay when it makes straight-line *chords* (in plan view) around a curved track. This enables longer bay lengths to be achieved, which cuts down costs and also helps to promote more even wear on the pantograph carbon strips.

The most common form of support & registration these days is the *cantilever* (shown), which has a simple triangular steel frame, along with insulators and other associated hardware providing a reasonable amount of adjustability.

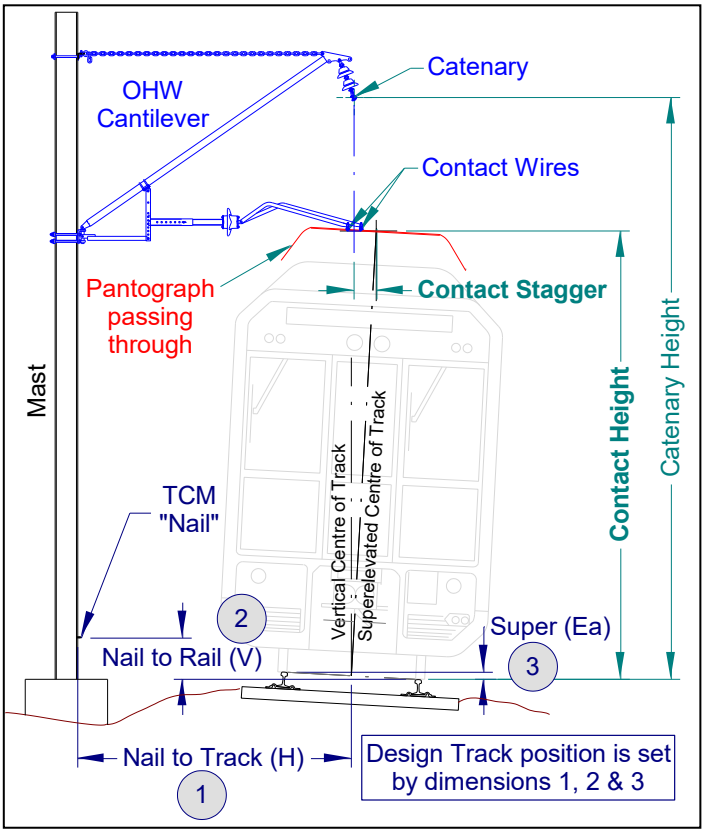


Figure 19 - OHW in relation to Track & Pantograph

The catenary, supported at about 6.5m above the track these days, is insulated by *support insulators* (or *suspension insulators*), which are normally made from porcelain. They have sufficient electrical insulation to withstand much higher voltages than the normal 1,500 volts (e.g. to help deal with huge lightning impulse voltages that may strike and travel along the conductors).

Likewise, the contact wire is held in place through *pull-off insulators* made from porcelain, or more recently from a special plastic resin, or sometimes even fibreglass has been used.

The contact wire is registered in position at regular intervals by *pull-off arms* (which are mostly shaped like a person's outstretched arm). These steel arms are designed to connect to a fitting – a *contact swivel clamp* – that then attaches to the wedge-shaped groove in the top of the contact wire. The other end of the arm then connects to insulator/s back towards the support structure.

The pull-off arm accurately positions the contact wire in a lateral sense above the track, to the desired *stagger*. This stagger is set to zig-zag typically 250mm to one side then 250mm to the other of the vertical track centreline on *straight track*, or 300mm to the high side of superelevated (inclined) track centreline on tighter *curved track* (shown in *Figure 19*).

Pull-off arms are specially shaped to clear all passing pantographs, and should pivot to allow some degree of contact uplift as each pantograph pushes up the contact wire when it passes by. Various pull-off arms in regulated OHW also need to pivot horizontally in sympathy with the longitudinal contact wire expansion (when hot) and contraction (when cold).

Figure 20 - Mk-2, Type 1 & 1A Cantilevers (Dapto to Kiama)

Within a long bay, there may be one (or even 2) *pull-off* locations, where the OHW catenary and contact wires are simply registered from the side (i.e. not supported) for pantograph security. Because of their simpler construction, pull-offs are cheaper than cantilevers, so they can help reduce initial construction and ongoing maintenance costs. However, their presence can sometimes also lead to undesirable contact wire upward movement problems with pantographs on fast trains, so they tend not to be used much these days. (It's better to support, support, support …)

Figure 20 shows a series of cantilevers supporting the single catenary / twin contact OHW on straight track with 67m bay lengths (the maximum length these days). The successive arms are positioned on opposite sides of the track to provide the zig-zag ±250mm stagger pattern.

The track itself is positioned in relation to a Track Control Marker (TCM), or *Nail* as we refer to it, installed on the track-face of the mast. A survey plaque is affixed to each structure, displaying information that includes measurements 1, 2 & 3 as shown in *Figure 19*. This represents the design location of the track, but the track is allowed to deviate from this position within its 3 associated tolerances, without upsetting *pantograph security*.

2.3.3 Support Structures

The support & registration arrangements (described above) are in turn held up by OHW *support structures*, such as *masts* and *portals*. These large steel structures are firmly supported from ground and are located at about 3m clear from the closest track. Portal structures can hold many support & registration cantilevers with the aid of one or more *drop verticals* suspended from the horizontal *portal bridge* and located adjacent to the specific track being serviced (positioned typically 2m laterally from the track).

All these structures are designed to cope with the applied weight, radial and wind loads coming from the overhead wiring conductors, etc.

Support structures are designed to be strong enough to handle gusting 160km/h wind speeds striking the structure itself and any attached bays of OHW conductors. They are also designed to be stiff enough to prevent too much deflection (flexing) under wind loads, which might otherwise lead to momentary excessive contact stagger excursions on pantographs. This in turn might lead to the loss of pantograph security, resulting in subsequent damage to pantograph/s and to many bays of OHW, and cause train delays for a significant time.

Alternatively, existing infrastructure, such as bridges and tunnels, can be used to provide such OHW support, by utilising special steel adaptor brackets to the existing structure. This can often save on the significant cost of OHW structures.

On straight track, cantilevers installed on OHW structures are typically spaced 67m apart, and this reduces to about 20m or so on tight track curves (down to about 200m track radius). Rarely do bay lengths exceed 73 metres. This upper limit comes about primarily because:

- The resulting catenary vertical sag becomes too much (needing taller structures), and/or
- The contact wire horizontal blowout (typically at 130km/h) encroaches its limit (of 381mm to the superelevated track centreline).

A squared law applies to the *catenary sag* – if you double the bay length, you make the sag 4 times as much. As a consequence, longer bays require much taller OHW support structures, and there is ultimately an economic limit to their height. (They are normally 7.5m, but can be up to about 8.5m high above the track level.) A squared law also applies to the *contact blowout* (mentioned before), with similar restrictions placed on bay lengths as a consequence.

2.3.4 Anchors

Anchor arrangements occur at both ends of the wire run. They allow the catenary and contact wires to be appropriately terminated and then tightened to their correct tensions.

Termination insulators, which are strong enough to hold the large wire tensions, are installed at anchors to provide the necessary electrical insulation of the wires (at 1500V) from the (somewhat earthed) steelwork of the anchor structure.

The catenary anchor height is normally a bit higher than the height of the supported catenary above a track, and the contact anchor height is normally about 1m higher than the in-running contact height (these days typically 7m above track for catenary and 6m for contact anchor).

Both anchors are usually placed about 3m laterally away from the closest track (to gain suitable clearance to passing trains).

Sometimes simple anchors can also be placed on walls, and they can even be located above the track, e.g. on the face of a tunnel.

The catenary and contact wires can be tensioned in one of 2 ways:

- ***Fixed-Anchored tension***. The ends of the wire runs are simply fixed in place. Unfortunately, this means the tensions in the wires change with temperature.
- ***Regulated tension***. One or both ends of the wire run have a tension regulator device attached (e.g. using a stack of weights with pulleys). The regulator device keeps the wire tension relatively constant, regardless of wire temperature, which is ideal (although their action must not be restricted, e.g. the weights must not bottom out to ground when hot and not rise into the pulleys above when cold).
  Note that if tension regulators are installed at both ends of a wire run, then it is essential to have a *fixed mid-point* (FMP) anchor located somewhere near the middle of the run. This simply locks both the catenary and contact wires from moving longitudinally, which in turn forces the tension regulators to move properly as temperature changes.

Both of the above technologies come with their own limitations, and these must be taken into account during the design and subsequent construction, operation and maintenance of the OHW, to ensure reliable train operations.

2.3.5 Overlaps

When a wire run must end, it is taken over by the next wire run at an *overlap* (O/L). In this way, the train's pantographs can smoothly transition from the contact wire of one run to the next, even at high speed, without causing any interruption to the train's electrical power supply. The term *airgap* was also used in the past. See *Figure 41* further on for overlaps.

An overlap can also provide for electrical sectioning – for feeding power to, or alternatively isolating, the OHW 2 electrical sections. In this situation there is usually a 250 or 300mm horizontal spacing or separation (air gap if you like) between both sets of wires in the overlap bay. In this case, each passing pantograph momentarily shorts out the 2 electrical sections for a short distance of a few metres as it passes through.

An overlap typically requires 3 (or even 4) bays of OHW for its establishment, meaning that they can occupy fairly long track distances (of 100m to 200m). This can sometimes be a problem (which can be solved by installing a section insulator – see below).

Some special (old) overlaps only required 1 bay, with anchors installed at each end for terminating the 2 runs of catenary and contact wires, at anchor points located directly above the track. This required very strong structures that could handle the significant anchor loads.

2.3.6 Section Insulators

A *section insulator* (SI) provides much of the functionality of an overlap, but because it occupies far less space (up to 2m long and 500mm wide), it can be installed virtually anywhere in a wire run, at a location where there is the need to provide electrical sectioning.

Like an overlap, an SI allows the train's pantographs to power through in a smooth path (but maybe not quite as smooth as an overlap). However, the distance where the 2 electrical sections are shorted out by a pantograph is much smaller than for an overlap, and this can have distinct advantages in certain circumstances (see in particular *Section 3.6.0.5*, subsection *Damage Due to Pantograph Bridging*).

The weight of the section insulator is supported by guy wires from the catenary, and these guy wires also help to align the body of the SI for proper pantograph interaction at speed.

Unfortunately, SIs do require more regular maintenance and in particular, they need to be checked for proper longitudinal and lateral alignment at the contact wire level. If there's even a small amount of misalignment, the impact from the huge number of (uplifting) pantographs passing through each day can cause some further misalignment, and ultimately start damaging pantographs and/or the SI itself, which will eventually stop trains. (The degree of misalignment can often be *heard* as fast pantographs pass through.)

2.3.7 Switches

A 1500 volt *switch* is employed when OHW, at a particular location, is in need of convenient electrical isolation from time to time.

A switch is usually installed on an OHW mast or portal leg, located clear of passing trains but close enough to make necessary local electrical connections (via. aerial wires or 1500V cables) to the two associated OHW electrical sections being switched.

The main switch mechanism is usually installed at about catenary wire height (roughly 6m or so above track level), which usually places their exposed electrical connections well away from people below.

The elevated switch is connected to a long vertical operating rod which then connects lower down to an operating handle located about 1m above ground level for convenience. The operator stands on an *equipotential mat* to prevent any chance of electric shock due to the unlikely event of malfunctioning switch insulators.

In addition, some switches can be *remotely controlled* if a suitable motor drive (with power and communications equipment) is also installed near the handle mechanism. It can then be controlled from the Electrical Operating Centre located at Central Station.

If the switch is located immediately next to the OHW, bare aerial feeders are used to make the connection to the OHW. Alternatively, if the switch is located a reasonable distance away from the OHW, this usually requires 1500V cables to be installed from the switch onto a portal bridge and over to a *cable-to-aerial termination* point located adjacent to (above) the remote OHW, with a short bare aerial connection then launched from it to connect to the OHW.

The bare aerial feeders to the OHW must have sufficient slack to allow for any likely OHW conductor movements without causing fatigue of the wires. But these wires should not be so long as to cause it to short out on nearby equipment or OHW structure under strong winds.

In addition to isolating the two OHW electrical sections, some switches can also connect one of the electrical sections to the track below, to help make the OHW safe to work on (and it then becomes *isolated & rail-connected*). There are also situations that employ *switch pairs* (2 switches located side by side and electrically interconnected) which can allow the OHW to be isolated and have either or both OHW sections selectively connected to rail.

It is important that switches not carry any current when they are opened, otherwise some significant arcing at the contacts will result during the opening, and this may cause damage or other problems. To avoid this, there's a switch operating protocol that must be strictly carried out each time.

2.3.8 Feeding

Feeding power to the OHW takes place at substations and sectioning huts. 1500V cables and/or aerial feeders are used to connect them to the OHW in a way similar to switching.

Aside:

Substation (S/S).
Substations are buildings that house certain electrical equipment which takes power from the high voltage ac network (typically at 33kVor 66kV), then transforms it to a lower voltage and rectifies this for the 1500V dc OHW system. They also provide a number of high speed dc circuit breakers (DCCBs), which can electrically help to protect trains, protect the OHW in case of an electrical fault somewhere in the system, and isolate the OHW during routine maintenance work or during train incidents. The spacing of substations supplying power can vary between 4km and 15km apart, depending on the type of trains and their power demand, track grades, conductor sizes, the presence of intermediate sectioning huts (see below), etc.

Sectioning Hut (S/H).
Sectioning huts are often located between substations. They are not configured to inject power from the HV ac system. Instead they focus on the dc side only, and house the same high speed dc circuit breakers as substations (with the same dc electrical protection functionality). But these circuit breakers are configured so that they electrically tie

together the various dc OHW sections being fed, to a common busbar within the S/H. This is done primarily to improve the voltage regulation at the trains. (They lower the circuit resistance to the trains and thereby keep the voltage on each moving train closer to the required 1500 volts.) In doing so, sectioning huts allow the more expensive substations to be spaced further apart than they would otherwise be, thereby making it a more economical outcome. (This is provided there's adequate power available from the distant substations to feed modern power-hungry trains.)

For more about this, refer to *Section 1.7.2* and *Section 6.1*.

Feeding from a substation or sectioning hut building to the various OHW electrical sections is usually carried out using 1500V *cables*. But in the past, this had also been achieved using *bare aerial wires* if the building was located next to the tracks being fed. The aerial feed approach is no longer used because of safety concerns (notably the hazardous situation where live feeders pass over a track that has been isolated to work on, and also the risk of these feeders falling to ground outside the S/S or S/H without tripping the electrical protection).

The 1500V cables can be installed underground (and mostly out of harm's way) or in steel troughing (which offers some degree of protection from falling objects and vehicles). Cable derating needs to be considered in such situations, because any heat generated by the cables (when passing heavy current) and/or by the ambient conditions (temperature, sunlight, lack of cooling wind, etc.) is more difficult to dissipate quickly in this situation. As it is with the OHW conductors, heat is also the enemy of cables.

Note:

From a designer's perspective, *feeding* or *switching* arrangements can often seem to take up an inordinate amount of time to design. There are some standard arrangements on offer that can *accurately* describe the construction of certain rather simple situations, e.g. feeding from a PP mast. However, there can be many site-specific variables and feeding requirements (especially when more than 2 tracks are involved), and this may make the accurate description, on design drawings showing exactly what to build, a much more difficult exercise, and lead to unique feeding designs down to the "nuts and bolts" (and thus the additional design burden). Very rarely can you simply "rubber stamp" a design based on some other design situation, and expect it to have exactly the same fittings and configuration for it to be accurately constructed.

2.3.9 Surge Protection

Surge protection is mainly intended to protect certain vulnerable OHW equipment – most notably the 1500V feeder cables – from permanent damage if and when lightning strikes the OHW conductors and travels along it to possibly jeopardise this vital equipment.

"Surge arresters" are compact units (up to ~300mm tall), designed to do 2 important things:

- They limit any surge ***voltage*** across the equipment being protected (to less than just above 2,000 volts), and
- They divert the surge ***current*** to earth (and in doing so, they dissipate the surge energy, and reduce the likelihood or extent of surge damage to other nearby OHW equipment).

Previously, these units had been referred to as "surge diverters", "lightning arrestors", etc.

2.3.10 Over-Run Protection

Over-run protection, where required, is installed to help deal with a train pantograph if a train ventures into an area that has no OHW to control the pantograph's uplift.

This can happen at certain train car maintenance sheds, and at some crucial areas of the network where track spurs can redirect or derail trains to prevent them entering dangerous areas, e.g. Platform 23 at Central Station (bi-directional operations for the Airport Line).

Fortunately, the need for this type of protection is fairly limited in the electrified network.

Over-run protection is achieved by configuring various other equipment elements, notably conductors, support & registration, support structures, anchors and section insulators.

2.3.11 Signs

As usual, *signs* convey important information – in this case about the OHW system and its specific requirements or hazards.

Signs must be acknowledged as an important asset, and so should be maintained for the proper operation of the OHW system.

2.3.12 (Bonding)

In Sydney's dc system, the *traction return* circuit connects the running rails of each track to the negative 1500 volts supplied from the nearby substation/s. So, the track rails provide the means of returning the current delivered by the OHW to nearby trains, back to the substation/s and thus completing the electrical circuit. The 2 key ideas here are:

- The rail *electrical resistance* should be minimised. This can be done by electrically paralleling tracks. In this way, the rail *voltage drop* over distance away from the substations can be minimised (which in turn helps deliver more voltage to the trains).
- The rails of the tracks are mostly intended to be *isolated* from *earth*, by resting on wooden sleepers, concrete sleepers, special plastic pads or *cologne eggs*, etc. This isolation is done to try to prevent *stray dc currents* from finding alternative paths (i.e. other than the intended tracks), via earth, back to the substations. E.g. stray currents may find their way through nearby metal pipe lines and steel structures, which can cause *electrolysis corrosion* problems to this infrastructure, as well as other nasty outcomes over time.

Bonding is mostly to do with trying to protect the OHW system and its surroundings from the hazards of a 1500V high-current OHW system, should something go wrong. (Bonding is usually associated with the traction return circuit, but may involve alternate approaches.)

In the unlikely event of the 1500V insulators on support & registration or anchor equipment *not insulating*, the consequence can be a support structure livening up towards 1500V. If left, this can cause a safety risk for people nearby, and it can also cause electrolysis damage over time if not detected in a timely manner. This is very much to do with *risk management*.

Bonding is included in this document even though it's not part of the +1500V OHW system – it is important that it be understood and not ignored.

Much more comprehensive details of the above OHW categories are provided in *Chapter 3*. This includes describing specific standard equipment (both old and new), some theory on how they function, the problems that they overcome, etc.

2.4 THE ALL-IMPORTANT CONTACT WIRE

The most important component of any OHW system is the *contact wire*.

Almost every other functional category of the OHW system is there to allow (or enhance) the contact wire to perform its crucial task, which is:

> *to directly supply uninterrupted high magnitude electrical current at 1500 volts,*
> *to the train's several pantographs travelling at the defined track speed.*

In order to achieve this outcome, the contact wire must also control the vertical movement of each pantograph on a train, so as to prevent the OHW and pantograph becoming tangled and damaged.

The main OHW equipment categories are listed in the headings below, along with some reasons why these different functional aspects help the contact wire to do its job. (See *Chapter 3* for more extensive details.)

Figure 21 - Modern OHW with Twin Contacts

CONDUCTORS

The contact wire is held up by its supporting catenary wire and associated droppers, which help give the contact its flat (or near flat) profile shape throughout each bay, which in turn helps promote high speed and reliable train running. Most of the other *conductor* elements (including in-span feeders, knuckles, etc.), help contribute to the success of the contact wire to perform its task of supplying current to the pantographs. Even the tension in the conductors must always remain high enough so as to not cause problems under extremely windy conditions, or to reduce electrical clearances to nearby infrastructure, etc.

SUPPORT & REGISTRATION

The various support & registration (S&R) arrangements are there to physically support the catenary wire (which then supports the contact wire), and to register the contact wire's lateral stagger position in relation to the track, using special pull-off arms. This helps ensure the pantograph always stays on the contact wire, thus promoting security of train supply.

SUPPORT STRUCTURES

These are required so that the S&R arrangements have something to transfer their various heavy mechanical loadings to solid ground. (Importantly, this includes handling the contact wire's weight, as well as any radial and wind loading from the wire.)

ANCHORS

The anchors apply high mechanical tension to the catenary and contact wires throughout their run. The contact wire's tension is always kept high enough so that it can reliably interface with the uplifted train pantographs at speed, and can also limit the amount of blowout caused by strong cross winds, thus allowing uninterrupted current supply to the train. The tension in the catenary should be large enough to prevent too much dynamic movement, especially at mid-bay, and as wind disturbs this wire and the connected contact wire below it.

OVERLAPS & SECTION INSULATORS

When one wire run finishes, it needs to be taken over by another, whilst allowing a smooth pantograph transition from one contact wire to the next. The *overlap* performs this function, and is needed to allow reliable train running.

A section insulator provides the functionality of an overlap, but allows convenient electrical sectioning anywhere within one run if required without the need of an additional (and expensive) overlap.

SWITCHES & FEEDING

These are required to provide electrical sectioning (isolation) to the OHW runs. They control the feeding paths for the trains' electrical currents to flow, and ultimately this current flows via the contact wire to pantograph. (The dc circuit breakers within substations and sectioning huts that feed power to the OHW, provide the necessary important electrical protection to the OHW.)

SURGE PROTECTION

This helps maintain reliability in case of lightning storms, so that the various components of the OHW system – particularly the 1500V cables – are more likely to remain undamaged if the OHW is struck by lightning. In doing so, this allows the contact wire to continue to do its job.

OVER-RUN PROTECTION

This helps control the train's pantograph in case the train ventures into an unwired section, again helping to improve the reliability so the main contact wire remains intact.

Probably the area most likely to cause damage – to the OHW and to the pantographs – occurs at the *turnouts* to the multitude of track *junctions* located throughout the network.

At these track turnouts, each pantograph on a train must reliably take up an adjacent contact wire, and run on it while leaving the previous contact wire. This should be achieved without snagging either wire or causing mechanical damage, excessive mechanical wear on the contact wire/s or arcing damage. Pantograph damage can also result.

And by their very nature, junctions / turnouts involve at least 2 wire runs, so any significant damage to the wire (e.g. due to tangled pantograph), can quickly spread to affect the OHW for adjacent tracks and cause trains to stop running, for a considerable length of time.

Refer to *Section 5.1.29*, *OHW Design at Turnouts* for more.

The other important aspect to the contact wire is that *it controls the height of a pantograph*. If the contact wire height is altered and/or it's in a fixed-anchored system (where the contact height towards mid-bay varies with temperature), the pantograph height and its lateral distances should be checked out for suitable clearances, especially to station awnings, overline bridges and tunnel linings.

The *design* of the OHW should normally confirm its suitability in this regard. Indeed, the design task is extremely important to the ongoing reliable functioning of OHW, and it should never be underestimated or dismissed as being a trivial or irrelevant activity.

2.5 IMPORTANT TERMINOLOGY

This section includes a number of terms that need to be introduced or clarified at the start, so as to avoid confusion later on when reading the text. Even more clarification may be available by referring to the *Glossary of OHW & Related Terms* in *Chapter 9*.

2.5.1 *Wire* versus *Cable*

The following definitions for *wire* and *cable* are used in this document. For additional details to that provided below, refer to *Section 3.8.0.5*, *Cable Size Versus Aerial Feeder Size*.

WIRE

The term *wire* refers to a single strand (in the case of contact wire) or multiple strands, of extruded metal formed into a somewhat circular cross-section shape and of some continuous length. See *Figure 22*.

Figure 22 - Wire

This forms an electrical *conductor* and provides the means of transmitting electrical current (at a certain voltage) from one place to another.

The metal used in OHW is normally copper or an alloy of copper, although steel has also been used for catenary wire in the past (but is almost phased out by now).

Notably, there is no outer (plastic or other) covering, and it is sometimes referred to as "bare" wire (I guess to emphasise this fact). For example, the copper catenary wires are all "hard-drawn bare copper" (HDBC). Indeed, the term "overhead *wiring*" primarily refers to the bare catenary and contact *wires* located above a track.

CABLE

The term *cable* refers to wire that is surrounded by one or more layers of insulation material, usually oil-impregnated paper (in the old days) or special plastic (these days). This makes it a much more complex item to make and to handle, and more expensive. Refer to *Figure 23*.

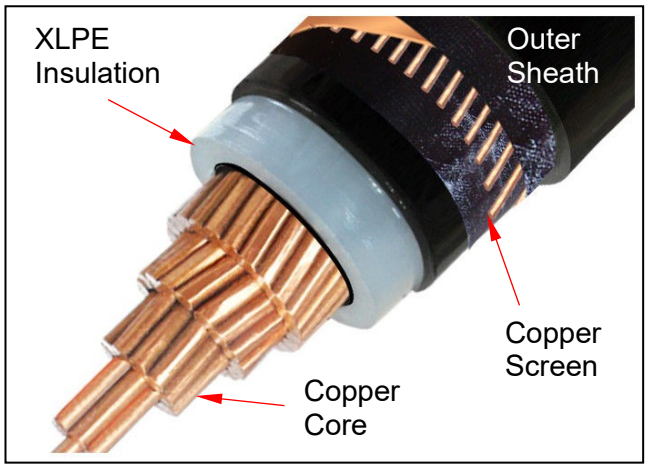


Figure 23 - Internal composition of XLPE Cable

This insulation provides a certain degree of protection to the surrounding environment from the low, medium or high voltage that the cable core is energized at (in this case 1.5kV).

For the past 40 years or so, 1500V cables have had the main insulation made from *cross-linked polyethylene* (XLPE), with additional outer layers of other plastics that help make the cable waterproof and give it some robustness during handling and when finally exposed to the outside world. (Note that XLPE insulation does not tolerate water ingress at all, so its terminated ends need to be suitably sealed using proprietary *cable termination kits*.)

Screened cables offer a single independent layer of copper wires that surround the main insulation, to help provide a screen or barrier to the outside world in case the cable is struck. With Sydney's OHW system, the screen is typically connected to substation Earth which, in

the case of an electrical fault, can also be quickly connected to substation Negative through the activation of the Rail Earth Contactor (REC). If some metallic object punctures the cable and shorts out from screen to the live core (e.g. a jack hammer), it provides a way of rapidly activating the electrical protection, through *over-current* or *rate-of-rise* ("delta-I") *protection*, to isolate this electrical fault.

Unscreened cables obviously have no such screen, and so are slightly smaller in diameter than their screened counterpart. Consequently, they are slightly less stiff and are therefore easier to manoeuvre into position.

1500V cables are generally used to transmit power between substation or sectioning hut out to the various OHW electrical sections (4 sections for 2 tracks). They are also sometimes used to feed current from local track-side switches to some remote OHW conductors.

The normal cable for feeding/switching to the OHW is 400mm² XLPE cable, rated at 3.8/6.6kV, with copper screen (of about 90mm² area). Other popular cable sizes used in the HV traction system include 240mm² and 90mm².

Unfortunately, the multiple layers of plastic etc. surrounding a cable tend to trap any heat generated when heavy current passes through the copper core, and this can lead to a significant derating on the conductor (i.e. it's not able to pass as much current before overheating). In contrast, bare wire can more freely dissipate any heat to the surroundings, so for the same copper cross-sectional area, bare wire can pass heavier current for longer periods of time than cable (although wire *under high mechanical tension* must not reach the 80 – 90°C annealing point). There's much more on this aspect later.

2.5.2 *Live, Dead, Isolated* and *Rail-Connected*

Alive or ***Live*** – is the term used to describe parts of the OHW system that are energized, typically at its operating voltage – in this case approximately +1500V.

Dead – normally applies to the ac system, and means disconnected from the source of electrical supply (and earthed).

Isolated – means the conductive parts of the OHW have been disconnected from all sources of electrical supply. This results in those parts being at some "floating" potential (not tied to +1500V). This condition by itself does ***not*** make the OHW safe to come near – see below.

Rail-Connected – is the term used to describe the situation where a piece of OHW equipment (typically an OHW conductor) has been connected by heavy copper cable to traction return rail, thus making it electrically *shorted out*. This would firstly require disconnection from the electricity supply (i.e. *Isolated*), then testing to ensure there's no significant voltage on the equipment, before the rail connection/s can then be applied.

The correct term for this final condition is *Isolated and Rail-Connected*. Shorting the OHW directly to the track's traction rail/s helps make the OHW electrically safe to work on. Because the isolated OHW can sometimes continue for kilometres, this type of connection should be made at a number of locations throughout this length to more effectively render it safe to work on over that extent. This would likely include any locations that offer points of supply (usually at both ends and maybe elsewhere in between). It is important to be able to visually see these connections too. Refer to the safety standards for current requirements.

Floating sections are portions of the OHW conductors that, due to insulators being cut in, are not connected to the energized OHW circuit, so their voltage can fluctuate (depending on the presence of nearby energized circuits, leaky insulators, etc.). Floating sections are normally *not permitted in the OHW*. While it might seem that floating sections could be a good thing (i.e. less energized OHW exposure), it leaves doubt as to what voltage the section might actually be at (because it is not rail-connected), and therefore it can remain unsafe.

2.5.3 *Fixed-Anchored* versus *Regulated* OHW

There are 2 ways of applying high mechanical tensions into the OHW catenary and contact wires: *Fixed-Anchored Tension* and *Regulated Tension*.

- ***Fixed-Anchored Tension (F/A)*** – gets its name from the way both ends of a particular wire run are simply *fixed* (held) at an anchor location, e.g. at a mast with guy wire to ground, or wall, etc. The consequence of this approach is that the wire tension will vary with temperature. (Note that the contact wire's tension changes dramatically.)
  It's an older but simpler technology, and is cheaper to install because the ends of the long wire runs are simply anchored with minimal parts. It is quite suitable for tunnel environments (even today), provided it has been well designed and built and is properly maintained. However, its relatively poor behaviour in response to extreme hot and cold temperatures limits its performance, particularly outside in the open route. This is especially true of the all-important pantograph/contact wire interface at high speed.
- ***Regulated Tension*** – is what results when one or both ends of a conductor are connected to a *tension regulator*, which provides a constant design tension (within a certain tolerance). In Sydney, a tension regulator most often consists of a stack of weights that are installed from an anchor mast – the number of discrete weights in the stack dictates the applied tension. These weights lower when the wire is hot (the wire extends its length) and they rise when the wire is cold (the wire contracts). Other types of tension regulators are or have been available to perform the same function. Elsewhere, regulated tension is sometimes also referred to as "Constant Tension" or "Auto-Tension".
  It's a more recent technology (since the 1960s for Sydney).
  In providing a relatively constant conductor tension regardless of temperature, it offers vastly superior performance in a few regards. Unfortunately, it cannot readily be installed inside long tunnels (due mainly to limited tunnel head room above trains, and the need for suitable locations where tension regulators can be installed). But it remains, by far, the best way of tensioning OHW in the open route.

Refer to *Figure 24* which compares these 2 modes of tensioning:

a) A bay of *fixed-anchored OHW* – here the conductors move *up and down* with temperature changes about a normal (21°C) position (giving a flat contact profile).

b) A bay of *regulated OHW* – here the conductors move *longitudinally one way or other* with temperature changes about a normal (21 °C) position (with support cantilever perpendicular to track).

Note:

As mentioned in *Section 2* (and *Figure 11*), the usual 10:1 magnified vertical scale is used in *Figure 24* – this helps to emphasise what's happening in the more critical vertical sense (see *Figure 500* much later on for how this approach compares). So, this should be borne in mind when comparing these 2 cases – Fixed-Anchored versus Regulated Tension OHW behaviour.

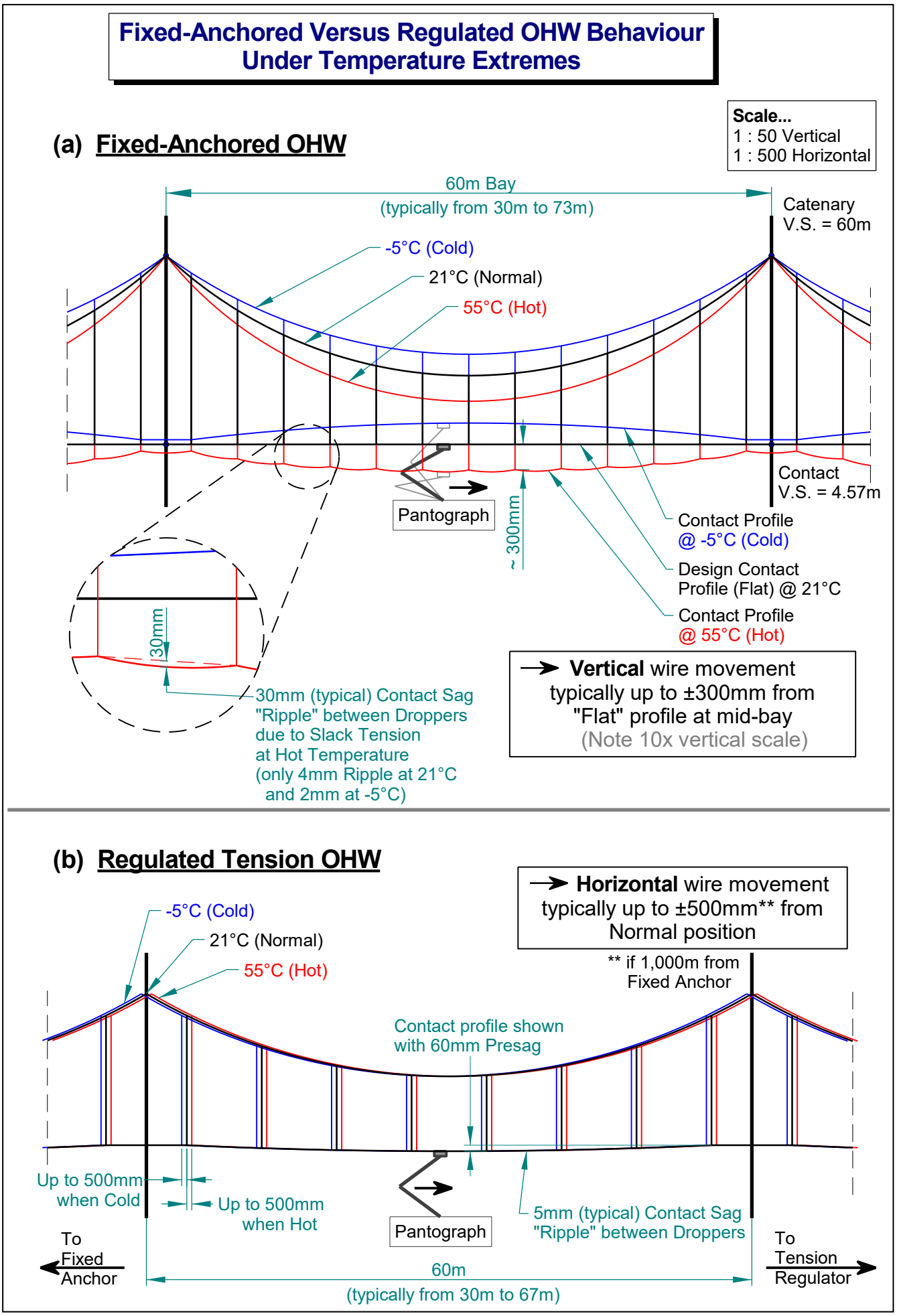


Figure 24 - Fixed-Anchored versus Regulated OHW behaviour comparison

The amount of expansion and contraction of the copper catenary and contact wire lengths due to temperature changes have different effects on these 2 types of OHW systems.

In case a), the ±300mm vertical displacement in a 60m bay is quite acceptable for low to medium speed current collection.

In case b), note the non-flat regulated contact wire which lowers slightly towards mid-bay. This *presag* shape (amounting to 60mm lowering in this 60 m bay) is deliberate, as this improves pantograph interaction during high speed train operation. Refer to *Section 3.1.2.5*, *Contact Wire "Hog" & "Presag"* for more details.

You can see by this diagram how much better the regulated OHW behaves than its fixed-anchored counterpart. Any vertical wire movement within each bay needs to be carefully considered and dealt with during the design of the OHW, as there can be several adverse outcomes if not properly designed. So, in this sense the regulated OHW is a far superior system. Having said that, the simple fixed-anchored OHW is quite suitable inside tunnels where temperatures aren't as extreme, the train speeds are generally lower and the headroom space is limited (making it more difficult to install regulated equipment).

If a contact wire *creeps* (permanently stretches over time) – which can sometimes occur – then there are different outcomes with the 2 tensioning systems.

- In a *fixed-anchored* OHW system, the extra length in that stretched wire is apportioned over all the bays in that tension length, which leads to a slight but permanent tension loss through all bays (that is, until corrected, which is fairly straight forward to bring about). However, in the meantime, the loss of tension can lead to various complications (discussed later).
- In a *regulated* OHW system, that extra wire length is taken up at the tension regulator, which, these days, is a set of weights. In this case, with 3 pulleys involved, that weight stack lowers by 3 times the amount of wire stretch. This can lead to a different set of complications, but this situation can be readily noted during patrols. Corrective adjustments are also relatively straight forward to implement.

Table 4 provides a summary of what I consider to be some of the pros and cons of each method of tensioning.

So generally speaking, regulated OHW is superior to fixed-anchored OHW. But there need to be suitable locations for the tension regulators to be installed. Also, the regularly-spaced supports (cantilevers) holding the regulated catenary and contact wires, need to allow these wires to move longitudinally without impediment, in response to their lengthening and shortening as the wire temperature changes (there's more on this in the next subsection).

The concept of *virtual span* is important to understand, as it plays a crucial role in the determination of the effects of temperature on conductor tension and subsequent consequences in a fixed-anchored OHW system. Refer to *Section 3.1.0.5*, *Virtual Span* for why this is so.

More details on the different effects of fixed-anchored versus regulated OHW are covered in many areas later in this document, e.g. in various subheadings of *Section 3.1.0.4* and *Section 3.1.0.5*, etc.

Aspect	Fixed-Anchored OHW	Regulated OHW
Conductor Metal Strength	Need higher tensile strength to cope with cold tensions. But most of the time the tension is much reduced and indeed very low (slack) at hot temperatures.	Reasonable tensile strength needed for tensions up to 3:1 safety factor. Also, this high tension remains high all the time.
Thermal Performance	OK.	Far superior.
Current Rating	OK.	Far superior (about twice the amount).
Tension Change	Wide tension change with temperature, particularly with the contact wire.	Negligible.
Catenary Height Restrictions	Need greater system depth (catenary to contact height) to allow for additional catenary sag when hot.	Generally nil.
Contact Height Restrictions	Need greater height to allow for additional catenary sag when hot, especially inside tunnels.	Simpler & more stable height outcomes.
Anchor Equipment	Simple & relatively inexpensive at both ends of wire run.	More complicated tension regulators at one end, or at both ends of wire run (with fixed mid-point anchor).
Support & Registration Equipment	Simple & relatively inexpensive.	More complicated (must swing to allow wires to move horizontally with temperature – this partly restricts tension lengths to no more than about 1,000m).
Performance with High Train Speeds	Generally poor. Arcing if pantograph disconnects – more prominent at hot temperatures at pull-off arms.	Good, depending on applied conductor tensions (the higher the better). No or very little arcing.
Contact Wire Life	OK, but kinks & wear at pull-off arms reduce wire life.	Superior life span, with relatively uniform wear throughout wire run. But any areas of worn contact wire will have increased stress (Tension/Area).
Maintenance Inspections	Generally hands-on examinations needed regularly (typ. 4 yearly).	Generally hands-on examinations less frequently (typ. 8 yearly).
Effect of Wind on Conductors (Blowout)	Blowout is affected by low wire tension when hot & high wind speeds. *Virtual span* is important.	Blowout is much better controlled, which improves reliability.
Effect on installed Section Insulator in Bay	Good performance at slower pantograph speeds, but performance affected by temperature (esp. hot days).	Superior control of pantograph interacting with SI, especially at higher train speeds.

Table 4 - Comparison of Fixed-Anchored & Regulated OHW characteristics

2.5.4 Along-Track Wire Movement

One of the few negative aspects to the wires being ***regulated*** is that every support & registration location needs to be capable of allowing the catenary & contact wires the freedom they need to move in the *along-track* direction as these wires extend in length (when hot) and contract (when cold).

This *along-track wire movement* is a progressive thing – the movement depends on how far the location is from a fixed anchor location (where the wire is locked from such movement). This movement can be anything up to about ±500mm from the design position perpendicular to track, as shown in *Figure 24*. In addition, *Figure 222* (further on) may help to comprehend what this means, and *Table 12* (also further on) should give an appreciation of how much copper expands and contracts with changes in temperature.

There are 2 main things that can be affected by large amounts of wire movement:

- The way of allowing this movement to take place must not alter the *tension* in the wires to any significant degree (this *tension loss* issue is discussed later in *Section 3.4.1.5*, *Tension Loss in Regulated OHW*).
- The contact wire's lateral *stagger* at each registration location is usually affected by this wire movement, but this stagger must remain within its stipulated tolerance. Refer to *Section 3.2.0.5*, *Stagger Change with Regulated Contact Wire*.

MOVEMENT AT CATENARY SUPPORT

The longitudinal movement can most often be accommodated using special *cantilever* frames that pivot horizontally 2m or 3m further back at the support structure (which is usually a drop vertical or a mast, respectively).

Special *tunnel cantilevers* are more compact units that can be used in the confined spaces of tunnels, etc. This is where the height difference between catenary and contact wires (the *system depth*) is relatively shallow.

If the amount of catenary wire movement is small (e.g. typically within 100m of a fixed anchor location), then the longitudinal *swing* of a pair of suspension insulators (about 450mm long) can be enough to provide the necessary longitudinal freedom for the catenary wire, without affecting the catenary height too much and causing problems.

Also, special *catenary rollers* can be used where there is limited catenary height (such as under a bridge). However, there are special limitations when using these rollers (see *Section 3.2.5.4*, *Catenary Rollers*).

MOVEMENT AT CONTACT REGISTRATION

Free longitudinal movement of the attached contact wire is achieved either with the pull-off arm pivoting back at the pull-off insulator, or by rotation further back near the support structure (which is achieved by the cantilever arrangement).

Both these mechanisms are depicted in *Figure 222* (further on).

2.5.5 "Fixed-Anchored" versus "Fixed Anchor"

There can be some (understandable) confusion relating to the use of the term "fixed anchor" as used in Sydney's OHW system, which is unfortunate, so I will try to explain the situation.

There is ***Fixed-Anchored*** OHW, which relates to the *tensioning* of the OHW. This means that the OHW conductors at both ends are simply connected or *fixed* (connected to some solid anchoring point) at the anchor locations (see below). Therefore, the tension in the conductors varies with temperature.
In this case, the spelled-out term should be hyphenated, i.e. "Fixed-anchored" (or abbreviated to "F/A"). Fixed-anchored OHW is often contrasted against regulated OHW (where the tension remains the relatively constant regardless of temperature).

Also, there can be a ***Fixed Anchor***, which is a simple anchor that's fixed in position at the end of a wire run in either a regulated or a fixed-anchored OHW system. So sometimes there will be a fixed anchor at one end of a particular wire run, and a tension regulator at the other end.

At a fixed anchor location, we use the symbol "F" (in a regulated tension system) and "**F/A**" (in a fixed-anchored system). These symbols should appear on OHW layouts, tension length diagrams, etc. Still confused? Hopefully it will all become clear later in this document.

2.5.6 Mechanical Loads from OHW

The following three mechanical load terms crop up time and again throughout this document, so this is what they are. Refer to *Figure 25*.
See also *Section 3.2.0.5*, *OHW Loadings on S&R Arrangements* for more details.

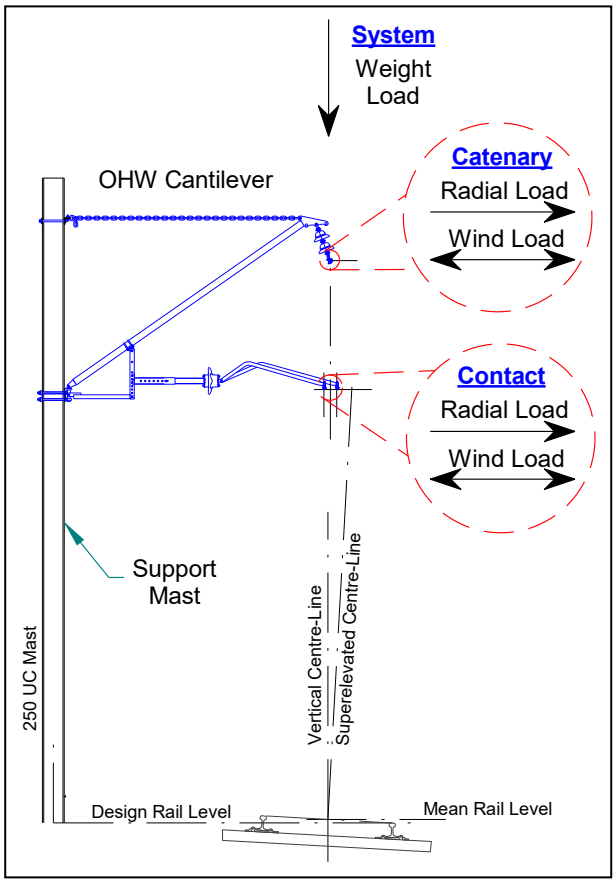


Figure 25 - OHW Conductor Loads

RADIAL LOAD

This is the lateral horizontal load caused by the tensioned catenary and contact wires changing their horizontal direction at a support & registration (S&R) location. The highly tensioned wire wants to get back to its straight-line condition, so the radial load is a consequence of holding the wire away from that straight line. (It's like plucking a guitar string – it takes an effort to pull the string sideways, as it wants to be straight.)

This change in wire direction is needed as the catenary and contact wires take on straight-line chords around a track curve. They can also result on straight track by simply alternating the direction of staggers ±250mm at successive S&R locations, and in other situations. See *Figure 61* further on for a bird's eye view of the cause of radial load.

Radial load needs to be transferred to the *support & registration equipment* and also the *support structure* – both need to be checked out for suitable strength and other requirements.

WIND LOAD

This horizontal wire load is caused by the wind striking each exposed catenary and contact wire horizontally in the bays of OHW. The wind speed used is typically 130km/h. Half the wire wind load in the bay goes to each adjacent registration point.

The wind can act in any direction it likes, but for OHW purposes the worst case is when the wind is acting perpendicular to the bay of wire, and it's assessed in the 2 opposite directions (as indicated by the arrow directions in *Figure 25* and also in *Figure 61*).

Like radial load, wind load also needs to be transferred to the S&R equipment and its support structure.

WEIGHT LOAD

At a *catenary support point* (S&R location), the vertical *weight load* comprises the combined weight of catenary wire, contact wire, in-span feeders, droppers, etc. in a bay – from the *catenary low point* in the previous bay to the catenary low point in the next bay. This is shown diagrammatically in *Figure 191* (much further on). It can even support the weight of a section insulator in a bay (the amount of load depends on its location within a bay).

The *catenary low-points* must be relative to the absolute catenary heights at each end of the bay, so it needs to include any track grade. The support with a higher catenary height (relative to horizon) takes proportionally more weight load, as the above figure shows.

At a *pull-off location*, which simply staggers the catenary and contact wires and so holds the radial and wind loads, there is normally *no weight load*.

Again, these loads need to be taken into account when designing suitable OHW support structures, etc.

2.5.7 Types of OHW Bays

Figure 26 is intended to help understand the terminology used for the various types of bays.

An OHW *bay length* is the horizontal distance from one catenary support point to the next catenary support point in a wire run. Bays can be as short as 20m or less, and up to a current maximum of about 67m (and 73m or so for the old fixed-anchored OHW system).

The wire run itself can have as few as 3 bays (in crossovers). There can be as many as 30 bays or so in regulated OHW. Fixed-anchored OHW runs have no real length restriction, other than for the need to establish overlaps at certain locations for electrical sectioning, or as a matter of prudence to limit the extent of any damage to the OHW should an incident occur. (The catenary and contact wires can be extended by *splicing* in additional lengths of these conductors, although the splice fittings then become an additional front line item to be maintained into the future, so this approach is totally discouraged for new OHW).

In the rare case of *contact-only* OHW, the bay length distance is between contact support points, but I think they can only be up to about 30m apart. (*Example:* Central Station – country platforms.)

For the majority of a wire run, the successive bays have the catenary wire supporting the contact wire at a height and profile that places it *In-Running* (IR). This allows the train's several pantographs to slide along the underside of the contact wire to collect current.

However, there are usually a few other types of bays in a wire run where the contact wire is partially or fully *Out-of-Running* (OOR).

Referring to *Figure 26*, bays can be configured as follows:

- ***Normal Bay***. This is where the contact wire is in-running throughout the bay. This is the usual situation.
- ***Overlap Bay***. An overlap requires the contact wire to begin to rise up at about mid-bay, from being in-running to become out-of-running. This transition occurs in the *overlap bay*. Viewed from the out-of-running support location at one end of the overlap bay, the contact wire typically lowers under its natural sag until it is at the in-running contact height, whence the droppers are required to control the in-running height and profile throughout the rest of this bay. (See *Section 3.5* if this doesn't make sense.)
- ***Pennant Bay***. This type of bay is less common in a wire run. It has the contact wire out-of-running (at a higher level) as it heads over to some other track, or over the same track, before then servicing another track, as it finally heads off towards anchor. Note that sometimes the catenary and contact wires are terminated together at some point within the bay, to then become a single catenary wire for easier manipulation during installation (as there's no need for the contact wire in this OOR situation). The proviso is that the single catenary wire can handle the combined tensions of both wires.
- ***Anchor Bay***. Here, the out-of-running contact and its catenary wire head off to anchor at the next support location – an anchor structure.

In terms of supporting the OHW, the ends of each bay can be thought of as either:

- ***In-Running*** – the contact wire supported here is at an in-running height.
- ***Out-of-Running*** – the contact wire is supported at a height that is sufficiently high enough to be considered out-of-running (typically 350mm or more above IR level).
- ***Anchor*** – the catenary and contact wire are terminated and anchored at this structure, well away from any pantograph.

Note that a *Normal Bay* can have 3 different *contact profiles* (per the inset in *Figure 26*):

- ***Hog*** – where the contact wire is deliberately *raised* towards mid-bay,
- ***Flat*** – a *straight line* contact wire throughout the bay, with no vertical profile (although it can be ramped to a different contact height at the other end of the bay), and
- ***Presag*** – where the contact wire is deliberately *lowered* towards mid-bay.

For further information on the contact profile, including the reasons for changing the profile, refer to *Section 3.1.2.5*, *Contact Wire "Hog" & "Presag"*.

Ultimately, the above configuration variables dictate the way the contact wire needs to be supported by regularly-spaced *droppers* from the catenary wire above it, for each and every bay in a wire run.

This contact *profile* is achieved by the *spacing* between, and *length* of, each dropper in each bay (and there can be up to about 30 droppers in long fixed-anchored bays with twin contact wires, or 20 droppers for regulated wire).

Refer to *Section 3.1.3*, *Droppers* for more details.

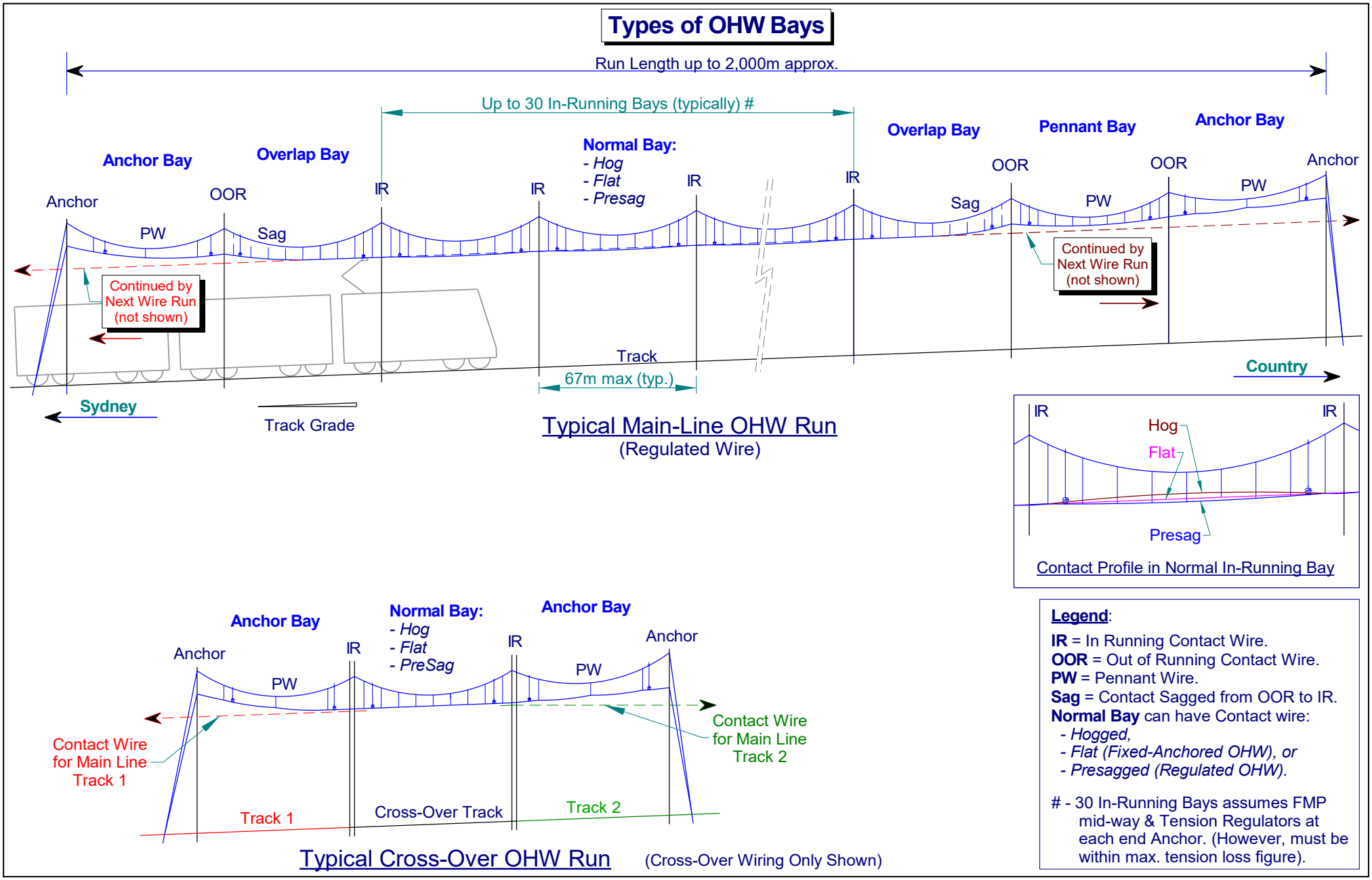


Figure 26 - Types of OHW Bays

2.5.8 Annealing

I've realised that throughout this document the term "annealing" keeps cropping up. This is mainly because its significant adverse effect on the copper conductors (catenary and contact wires) causes a fundamental limitation to the *current rating* of an OHW system. This in turn limits the amount and duration of electrical *power* that can be reliably delivered to the travelling trains, without causing permanent damage to these conductors. And there are other problems associated with annealing too. So, it may be helpful to describe what annealing is.

Annealing of a metal refers to the process of *softening* a metal, thus making it ductile. By annealing copper, the softened metal becomes easier to bend and to work with (especially using hand tools). It also turns a pinkish colour (which can sometimes be perceived as indicating a problem for the OHW – see *Section 5.1.14*, *Annealing & Discoloured Copper*).

Depending on the application, annealing the copper can be beneficial, but it can also be (and usually is) extremely detrimental to the OHW system.

Annealing is achieved by heating the copper up beyond the point where it *begins* to anneal, and this softening starts at about 80°C to 90°C. Fully annealed copper occurs at much higher temperatures (around 300°C), but it's where the copper *starts to anneal* that is of concern here, because *that's when its mechanical (tensile) strength begins to irreversibly diminish*.

OHW conductors are mostly made from hard-drawn copper (or copper alloy in some contact wires). The production of the individual strands that make up the wire requires a large copper billet to be forced through a series of extrusion *dies*, with each die producing a successively smaller circular diameter strand, until the final strand size is achieved. Forcing (drawing) the wire through each die *work hardens* the wire strands, and the final wire can be extremely hard as a result (thus the term "hard-drawn" copper).

So, by drawing the wire, the normally soft copper with very little tensile strength, becomes an extremely hard metal. This process gives it high tensile strength (breaking stress), and in the case of the contact wire, it can vastly improve its robustness and wear resistance when interacting with the carbon strips on train pantographs.

This is good for Sydney's dc OHW system, because the copper wires are not only excellent conductors of electricity (with low electrical resistance), they can also be installed with high mechanical tensions. This then delivers the benefits of less wire sag, less blowout in a bay with strong crosswinds, and improved pantograph interaction with the contact wire at high train speeds. For example, the working tension in a multi-stranded 25mm diameter (270mm^2) catenary can be 3 tonnes! (Its ultimate breaking load is more than 3 times this value.)

BUT … if the temperature in an OHW conductor approaches the point where it *begins* to anneal (around 90°C), then the copper *starts* to soften, and can begin to *permanently stretch* under these enormous applied tensions. This stretch can lead to all sorts of nasty effects in the OHW system and its interaction with train pantographs. And the effects are permanent – until noticed and somehow corrected later on (which can be a big and costly renewal exercise).

Design Paper No. 12 – "Determination of Limiting Average Temperatures of OHW", by G. Hunter in the 1990s, provides a useful insight into temperature limits for both fixed-anchored and regulated OHW. Included is the statement under the subheading "regulated OHW":

> "*Following tests by the Engineer of Tests, it appears that cyclic heating to 90°C for 3,800 cycles caused a 3% loss of tensile strength. This corresponds to about 10 years' service life. 90°C is therefore taken as the 'maximum hot bay temperature*'."

Amongst other reasons, it might be that the 80°C figure was adopted (instead of 90°C) so as to provide some small additional (but important) in-built level of assurance that the wire would be highly unlikely to start annealing when under its normal, but extremely high,

applied mechanical tensions? The *annealing temperature* is used when performing the various electrical load flow calculations that determine, or set limits on, the amount of power that can be reliably transferred through the OHW. This temperature limit can be seen further on in *Table 8 – Current Ratings* of various OHW systems (but as mentioned, the temperature limit can also be due to other reasons).

So, the main concern with OHW is that the temperatures in the tensioned conductors should not exceed 80°C. That's only 35C° above an extremely hot day of 45°C ambient temperature (which seems to be more prevalent these summer days), however this doesn't take into account the added temperature rises of a conductor due to solar radiation.

In fairly simple terms …

> The "natural" temperature of the wire (when passing no load current), is a result of the *ambient temperature* plus *solar radiation heating it* less *cross winds, rain or snow that can cool it*.
>
> So, the difference between this natural temperature and the 80°C or 90°C annealing temperature, represents the maximum *working temperature rise* allowed in the conductor when passing the *heavy current* for a certain *duration*, to power a nearby train (or trains).

Unfortunately, trains now demand so much more power than they used to, and the corresponding prolonged heavy current, both drawn and generated (when applying regenerative braking), can cause the OHW temperatures to approach this limit *without any alarm bells going off* ! (especially on hot days). That's why periodic, accurate OHW modelling with *load flow studies* – using worst-case timetable scenarios (including some diversification) – is vital to the reliable operation of trains.

The temperature rise in a conductor is a function of the current (squared) and the duration that this current flows, viz. $\Delta t = f(I^2, t)$. *Heavy* and *prolonged* current draw, resulting from rapid acceleration of heavy trains or when climbing steep grades, are both more likely to cause thermal problems to the OHW conductors. And these days, regenerative braking on trains turns these trains into generators of electricity (when braking), with the generated current again flowing back through the OHW, heating it up further in the process (and adding a degree of unpredictability about it).

Generally speaking, the OHW conductors are likely to be hottest outside substations where the current is drawn for the longest period of time, and diminishing with distance away from it. Sectioning huts also experience high temperatures, although not as great as at substations.

On the other hand … some wires that are not under any tension can be deliberately annealed to make them easier to shape to install. For instance, sometimes (rarely) feeder jumpers can benefit from being annealed when installed inside a tunnel, so as to form a particular shape in the relatively confined spaces of a tunnel. However – and this is important – any tell-tale signs of annealing *must be removed* or otherwise *managed*, to prevent questions of possible *annealing* being asked by others (in the future) – there's more on this in *Section 5.1.14*.

The process of working soft annealed copper, e.g. by bending or hammering it, begins to harden the copper (this is *work hardening*). Stretching the annealed wire also begins to work harden it, although its cross-sectional area will be reduced in the process which, under its working tension, can increase the stress in the wire and potentially weaken it.

There'll be much more to say on annealing at various places later in the document.

2.5.9 DC Leakage Currents

One of the unfortunate aspects of supplying trains with 1500V *dc* is that this "direct current", in certain situations and if not well controlled, can cause several nasty side effects on the OHW system and its surroundings. And some of these detrimental effects may not be

immediately obvious, but can show themselves many years later.

Dc *leakage currents* are, by their very definition, low level – in the order of micro-amps and possibly milliamps (but hopefully not amps). Refer to *Section 3.12*, *(Bonding)*.

Leakage currents can occur in the following *situations*:

- Across any *electrical insulation*, notably on the surface of the various 1500V insulators (from live 1500V to earth or negative return). Pollution build-up on the surface of insulators can reduce the surface resistance and allow greater leakage currents to flow (this is even more so in humid conditions). Leakage currents can also pass through insulation via any hairline cracks in the insulation.
- The *train tracks* leaking dc current through the ballast into earth, thence back to the supplying substation. The *negative return path* back to the substation (-1500V) is via the rails of one or more tracks, and depending on the amount of dc current flowing in these rails, there can be significant (but varying) voltage on the rails relative to earth (voltage is due to the rail resistance). This rail voltage can drive leakage currents back through the earth via the ballast. (The better/higher the ballast resistance the lower this leakage will be.) See *Section 3.1.0.5*, *Energy to Train*. (Note that this particular aspect is outside the control of the OHW system.)

Adverse effects include:

- *Corrosion*. Steel parts in the path of the leakage current can be corroded. This can include any line-side fencing (see *Figure 712* much further on), underground pipework, etc. Apparently, some forms of stainless steel can also be affected over time by the passing of even low levels of dc current (as detailed later in this document).
- *Flashover* of insulation (if sufficient current passes).

For more details, refer to *Section 5.1.18*, *Insulation to Minimise Leakage Currents*.

2.5.10 "Bonding" is Not "Earthing"

In Sydney's OHW system, the OHW supplies +ve 1500V dc from substation/s to the trains. The running rails of each track form the *traction return path* that takes the current, drawn by the trains, back to the substation/s at -ve 1500V, thus completing the circuit.

For most of the rail system, both rails of each track rest on timber or concrete *sleepers* that then rest on *ballast*, and both of these items offer some reasonable degree of electrical insulation of the very long steel rails from earth. This is important to the dc system.

In this imperfect world, some current leakage can occur to earth (more so in wet conditions, if the condition of the ballast is poor, and/or if the rails are imbedded in mud, etc.). But apparently some small level of distributed track resistance to earth actually helps keep the *rail negative potential* (rail voltage) at a level that's *close to earth potential*, which can be helpful.

Bonding essentially entails connecting certain unenergized equipment (such as an OHW mast), by heavy gauge wire, to the traction return rail, normally with a spark gap device connected in series. So, if a fault occurs which livens up that equipment to +1500V, the spark gap shorts out, enabling this bonding connection to - 1500V track rail to produce enough fault current so that the dc circuit breakers at the nearby substation and/or sectioning hut trip. This opens the circuit to render the situation safer.

Due to important dc electrolysis corrosion considerations, the OHW support structures, etc. are deliberately *not earthed*. If the structure is bonded to track, then the spark gap is installed to help in this regard.

With the 1500V dc OHW system, *bonding* does *not* mean *earthing* (although some electricians unfamiliar with the rail environment may find this hard to comprehend). Earthing has more to do with an ac electrical system.

If an earthing wire is inadvertently connected to a bonding circuit, it can cause increased stray dc current to flow in all sorts of unintended places, which could have safety implications!

One of the few elements of the OHW system to be earthed are surge arrester down leads (cables), which are intended to immediately direct any lightning surge current down to earth and away from other sensitive OHW infrastructure, to minimise any further damage.

I understand that special *Rail-Earth Contactors* (RECs) located inside traction substations and sectioning huts, are designed to help deal with electrical faults on the dc system (refer to *Section 6.1.3* for more). If they detect a higher-than-normal voltage between rail and earth (likely indicating a fault somewhere "out there"), the contactor closes and connects the -1500V supply directly to substation or sectioning hut earth. This action aims to maximise any fault current that may be occurring, so as to more likely trip the circuit breaker/s and thereby isolate the fault on the train supply.

But the RECs should be closed only for a short duration until the cause of the fault is identified and corrected, because shorting rail to earth will likely increase the magnitude of any stray dc leakage currents too! So, the shorter the duration the better. (Electrical Control Centre will receive an indication that the REC has operated, thus requiring someone to check out any problems in the field urgently, and reset the REC.)

Refer to *Section 3.12*, *(Bonding)*.

2.5.11 "Lateral" versus "Longitudinal"

Throughout this document, the terms *lateral* and *longitudinal* crop up from time to time when describing the OHW.

Lateral here means in a direction *perpendicular to the track*. For instance, the contact wire is staggered laterally (held to one side or other of track) at each support & registration location.

Longitudinal means in the *direction of the track*. So, regulated OHW conductors move longitudinally as the catenary and contact wires expand and contract as temperature changes.

2.5.12 Application of Tolerances

THE TRAIN SYSTEM

Ignoring the signalling system for the moment (which has its own crucial story), there are 3 major interfacing elements needed for the safe and reliable operation of *electric* trains:

- Track
- Train (with its several raised pantographs)
- OHW contact wire

In this system with 3 interdependent elements, strict tolerances must be applied and adhered to in each element, otherwise a train's pantographs may no longer be securely controlled by the contact wire/s, and a huge amount of damage and consequent disruption to train operations can ensue. This is covered a bit further on in *Section 2.7*.

In regard to the OHW, the alignment of the contact wires needs to be designed, installed and operated within their stipulated tolerances, especially in terms of contact ***stagger*** (at supports and throughout each bay) and contact ***height***. After all, the contact wire must control the

upward-pushing pantographs in all situations, to prevent them from rising above this wire (and this is more challenging towards mid-bay where the wire is less well controlled).

Section 6.2.2.3, *Tolerances for OHW* (much further on) talks more on the importance and application of tolerances associated with the OHW contact wire (especially in relation to the track). This is particularly important during the design phase of any new OHW project, or when designing for alterations to existing OHW.

Section 6.3.2.2, *Pantograph Security* likewise talks of the need to keeping the in-running contact wire within its own limits from the centre of each of the train's several pantographs.

So, tolerances play a crucial role in the operation of the OHW, and they must be understood by those people involved in the design, construction and maintenance of this infrastructure.

CONSTRUCTION OF OHW INFRASTRUCTURE

Tolerances play an important role when design work is constructed in the field, or alterations are carried out to this infrastructure based on an approved design change.

If certain critical as-built measurements of the constructed or altered item are not within the stipulated *design tolerance*, then either:

- *The item should be changed to bring it within tolerance* (the preferred outcome), or
- *The design needs to be altered to suit what was built*. But this should be based on a documented assessment of the situation, including costs to change the item in the field, long-term effects of it being outside tolerance (e.g. on safety, reliability, additional ongoing costs, reduced life, etc.), and any other relevant aspects.

The measurements themselves need to be relevant and accurate because important decisions rely on this information. An accurate survey may be required for certain types of information (and the tolerance on the actual surveyed measurements should also be taken into account).

Ideally, the as-built design drawings are meant to be a record of what was constructed in the field, so they can be referred to later on for operations and maintenance, and for documenting subsequent changes down the track (so to speak). But this documentation takes effort, and it's not always done (there's often other critical works the designer and others must get on with).

Contractual agreements can be quite effective in this regard, to highlight the importance of handing over an accurate as-built design to the client at the end of the project.

2.5.13 "Down" & "Up" Track References

Trains heading *away* from Sydney generally travel on the *Down* track, and those heading *towards* Sydney are on the *Up* track. To aid this understanding, we were told to think of Sydney as being at the top of a hill, so trains heading *down* the hill are on the *Down* track.

See also *Section 6.2.1.1*.

2.5.14 "Sydney" & "Country" References

For direction reference, the terms *Sydney* and *Country* are often used:

- "To Sydney" means the direction on a track heading towards Sydney, and
- "To Country" is the direction heading away from Sydney out towards the country.

In OHW design work, various OHW cross-section drawings have their primary views normally drawn "with back to Sydney" (meaning looking *towards country*). Here, the Down track/s are on the left and the Up track/s are to their right on the drawing.

The reverse of the above is "with back to country" (meaning looking *towards Sydney*). For OHW design work, this reference is not normally used except in special circumstances where it is more meaningful to show this view.

So, the standard view is "with back to Sydney". *Figure 13* and *Figure 39* (further on) have views using these track references.

2.5.15 Independent Registration

This is the term used to describe the way an OHW run is supported and registered using arrangements that do not cross any other track, i.e. no cross spans to adjacent tracks (which used to be common practice with the older fixed-anchored OHW).

The purpose is to make the OHW for each track independent, so that a failure of OHW over one track is much less likely to impact train operations on adjacent tracks.

So, this prudent approach initiated in the 1980s, and requiring little additional cost, is aimed at minimising train disruptions. Refer to *Section 5.6.1* for a bit more on this.

2.6 Minimum Electrical Clearance

In this document there'll be reference to a "minimum electrical clearance" figure of 150mm, taken between energized parts of the OHW at +1500V and earth or rail return at -1500V.

It applies to all sorts of situations (to be described later on), so it's worthwhile mentioning its purpose and importance early on in this document. Situations include:

- The minimum clearance from contact wire down to the top of a train.
- The minimum clearance from the catenary wire up to the closest parts of an overline bridge or the like, in the worst case.
- The minimum distance between both ends of a single insulator that's connected to the live conductors and an earthed (or rail-connected) structure.
- Etc.

I was informed that the 150mm distance comes from early tests which determined that, if an *electric arc* should suddenly appear on the system (for whatever reason) between +1500V ("live") and -1500V (traction return), then having this distance as a minimum would more than likely cause the arc to *quickly self-extinguish*. This is an extremely important outcome for the OHW system.

So, if the clearance is below 150mm, the probability increases that an arc, if somehow established, may not self-extinguish, or may not extinguish quickly enough. This can be a bad outcome, especially if the dc circuit breakers cannot "see" and trip a low level fault current, which can still be in the low *thousands of amps* (but the dc circuit breakers are often set as high as 6,000 amps to reliably supply trains).

If an arc doesn't extinguish within about 1 second, it's likely to do considerable damage to the OHW equipment and/or the surroundings.

In certain *confined spaces* (e.g. an insulator installed in a pocket inside a tunnel), if an arc is established it can create lots of conductive ionised air, in which case this 150mm minimum distance may need to be increased so as to again ensure the arc is rapidly extinguished.

Achieving the 150mm minimum electrical clearance figure is a fundamental requirement when designing and constructing the OHW, and later on when maintaining it.

Section 5.1.24 has more information on the various clearances.

2.7 IN-RUNNING CONTACT WIRE

*Note that there may be some contention regarding whether the "**design**" track position or "**existing**" track position should be referred to when performing any lateral **stagger** measurements and assessments, notably dimension (c) below – for **Pantograph Security**.*

The following description is my understanding of how things were set up in the 1980s and how they should ideally operate – using the "design" track position & relying on stipulated track tolerances. If there is a pantograph incident, then by taking appropriate measurements from "reference nail" to track, this approach can help to quickly determine the cause (since most track is not rigidly fixed but can move about on ballast, hopefully within its tolerances).

*However, need to **consult the current Standards** for the latest approach to be used.*

2.7.1 Relation of OHW to Track

Figure 27 shows the difference between the *Design* position of track installed on ballast (in BLUE), against a possible *Actual* position (shown in GREEN). Referencing a Track Control Mark (TCM), there are 3 aspects that come into play, each with their own tolerances (tolerable "errors"):

1. Horizontal Offset
2. Rail Level
3. Track Superelevation

Hopefully this diagram will give an idea of how the track position can affect the all-important OHW *stagger*, and an understanding of the challenges of keeping the OHW in a position that can always control the train's pantographs.

Track tolerances (in addition to train tolerances) play a crucial role in trying to maintain *Pantograph Security* which is needed to run a reliable electric train service.

For more details see *Section 6.2.2.1*, *Design Track Position* as well as *Section 6.3.2.2*, *Pantograph Security*.

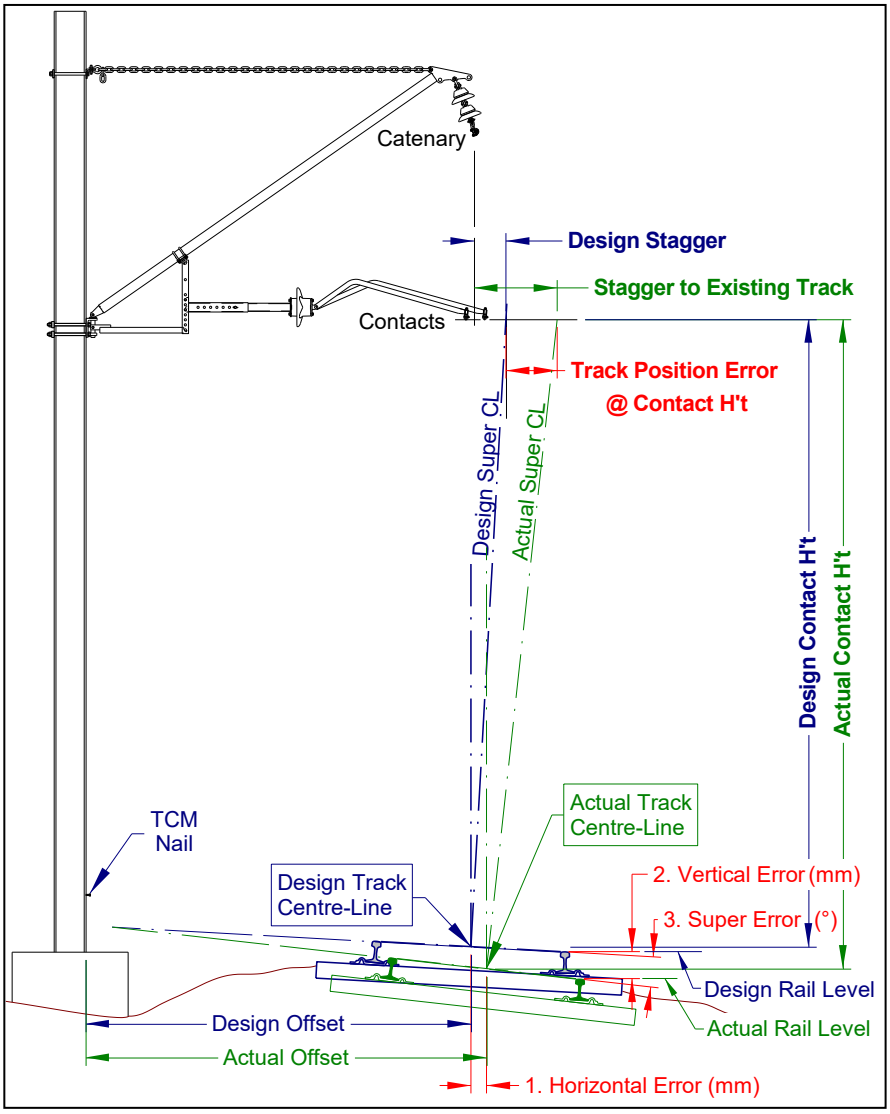


Figure 27 - How the Track can affect OHW alignment

2.7.2 In-Running Contact Zone

Figure 28 is an important diagram to understand. It's drawn to scale and shows the front view of one of Sydney's typical trains – a "Tangara" (apparently a local Aboriginal word meaning "to go").

> Most importantly, this diagram gives an idea of the zone (in red shading) where *at least one in-running contact wire must be located at all times, so as to both MECHANICALLY CONTROL and ELECTRICALLY FEED the train's pantographs.*

Although there are other aspects for trains travelling at higher speeds (including contact *ramp rate*), by having at least one in-running contact wire in this zone, it helps to assure that there should be no pantograph operation or power supply problems to the train.
(I understand that the new Metro line uses a lower standard contact height for single-deck trains, so the numbers on the diagram may not necessarily apply.)

In *Figure 28* the red shaded area is the *maximum operating envelope* for the in-running contact wire relative to the superelevated *design* position of the track.

If the contact wire ventures outside this red zone, then there's an increased risk that train running will be compromised. This is discussed below for the 3 main dimensions: **a**, **b** & **c** (the letters in brackets below refer to the relevant dimensions in *Figure 28*). Refer to standard EP-08000001-SP for more information.)

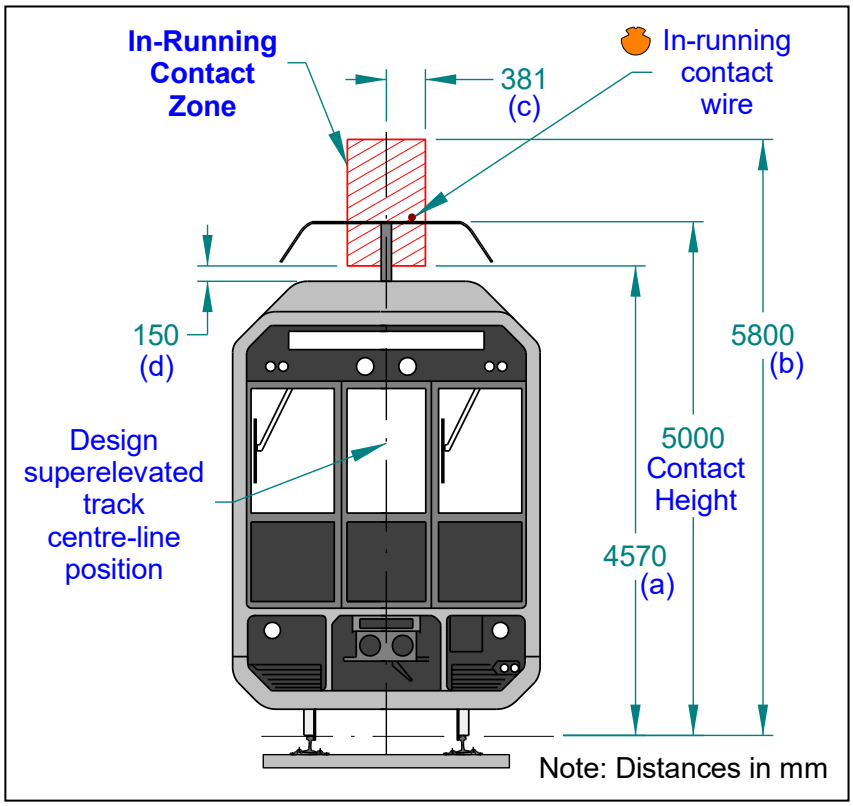


Figure 28 - The In-Running Contact Zone

MINIMUM CONTACT HEIGHT

4.57m – see dimension **(a)** in diagram. The design of the OHW must ensure that the contact wire relative to the *design track position* always keeps above 4.57m, which is only 150mm above the top of a double-deck train at 4.42m. [Refer to dimension (d) in *Figure 28*].

The importance of this 150mm minimum electrical clearance figure was described previously in the *Section 2.6*.

This situation is most likely to occur where the OHW needs to squeeze under a low structure, such as an overline bridge or inside a tunnel. It can also occur with wire sagging at mid-bay under hot conditions in fixed-anchored OHW.

In the case of the vertical distance above a train, the 150mm figure also allows for some dynamic vertical train movement (which then temporarily encroaches within 150mm) as the

train's suspension smooths the ride for passengers. [Note that the actual self-arcing distance (breakdown voltage) for 1500V is only about 1mm in dry air.]

There are only a very small number of existing tight locations (mostly in tunnels) where this 4.57m minimum height figure has needed to be lowered further to 4.52m (i.e. only 100mm above a train). I understand this relaxed lower limit probably came about when double-deck trains were first introduced into tunnels that were not designed for these taller trains, such as certain areas of the City Underground (even though the track would have also been lowered where possible at the time to help improve clearances). There are one or two tunnels in the Blue Mountains that also suffer these inadequate clearances, with 4.52 m needing to be tolerated there too. Yet another location is on the Up Shore track at North Sydney tunnels (immediately north of the Station), but this wire is now regulated so its behaviour when hot is under much better control these days.

All new designs use the 4.57m *absolute minimum* limit under worst case condition. Indeed, to instil confidence, adopting the much higher *standard contact height* of 5.0m for regulated OHW (5.03m for the old fixed-anchored OHW), was a prudent measure, at virtually no cost, that assures the wire is kept well above this lower height limit for the far majority of the network. That's less to worry about over time.

MAXIMUM CONTACT HEIGHT

5.8m – see dimension **(b)** in diagram. An increased contact height (of typically 5.4m) is needed at level crossings. Safety precautions dictate that there needs to be at least 1m clearance between the highest point on road vehicles (traversing the level crossing) and the lowest worst-case position of the contact wire in the path of the crossing vehicles. Refer to standard EP-08000012-SP for requirements at level crossings. See also *Section 6.4.5*.

The upper limit of 5.8m was stipulated as a typical maximum height for the OHW.

MAXIMUM HORIZONTAL OFFSET FROM TRACK

±381mm – see dimension **(c)** in diagram. The stagger of the in-running contact wire, plus any wire blowout resulting from high winds (typically at 130km/h), must not place the contact wire beyond ±381mm from the *design* superelevated centreline of the track at the contact wire height, at any location along the trackwork. (For twin contact systems, it could be argued that the 381mm is to the inner contact wire of the pair in order to control the pantograph, yielding a more relaxed outcome.)

This aspect is termed "Pantograph Security", and is discussed in detail in *Section 6.3.2.2*.

This is a strict requirement because the other tolerances of this "train system", i.e.
OHW tolerances + ***track tolerances*** + ***train tolerances***,
will take up what space is remaining on the top of a pantograph, up to its remote edges before the start of the downward diagonal horns (whence control of the pantograph is likely lost).

I mentioned the *design* position of track because there has to be an absolute reference point when so many tolerances are involved.

If a contact wire ventures to the outer edge of the pantograph, it is likely to no longer be able to control the significant upward vertical pressure of the pantograph (about 130 Newtons which is about 30 lb_F). This could result in the pantograph horn rising above the contact wire and damaging the various OHW hardware (droppers, pull-off arms, etc.), until the train finally stops, which could be up to 1 kilometre or so further on (depending on its speed, whether power is still available to the train or whether the train driver quickly notices a problem).

There are a number of videos around, taken from train roof, that show instances where the contact wire ventured out to the top corner of the pantograph, only to be "lost", and resulting

in significant damage to pantograph and OHW conductors (which typically flap about due to the huge electro-mechanical forces under a short circuit power surge).

I have attempted to show this sequence of events in *Figure 29*, assuming the contact wire is somehow located at the pantograph right-hand corner (Sequence 1) and with droppers (and in-span feeders and other hardware) located further on in the direction of train travel.

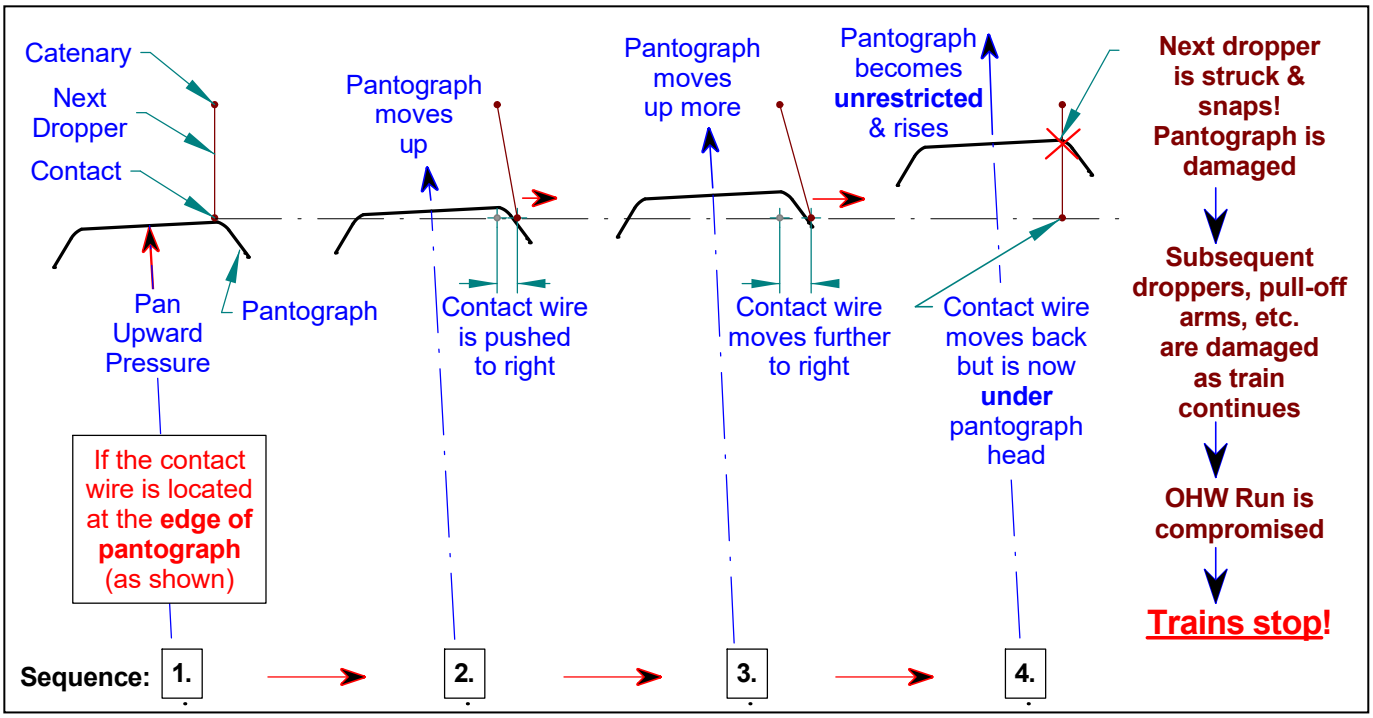

Catenary
Next Dropper
Contact
Pan Upward Pressure
Pantograph
If the contact wire is located at the edge of pantograph (as shown)
Pantograph moves up
Contact wire is pushed to right
Pantograph moves up more
Contact wire moves further to right
Pantograph becomes unrestricted & rises
Contact wire moves back but is now under pantograph head
Next dropper is struck & snaps! Pantograph is damaged
Subsequent droppers, pull-off arms, etc. are damaged as train continues
OHW Run is compromised
Trains stop!
Sequence: 1. 2. 3. 4.

Figure 29 - Sequence resulting in Contact Wire losing control of Pantograph

The consequent repair of OHW that's damaged in this way will take most of a day, if not more, and is likely to affect train running on that track and any adjacent tracks during that time!

Refer to *Figure 30* which is intended to show how close the contact wire (even located within its zone) can come to being lost if (in the highly unlikely event that) all the other tolerances occur *on the left side direction* and all at one time, i.e. no applied diversification. (Tolerances include *track* lateral, height and superelevation position, and *train bogie* movement and body roll, etc.)

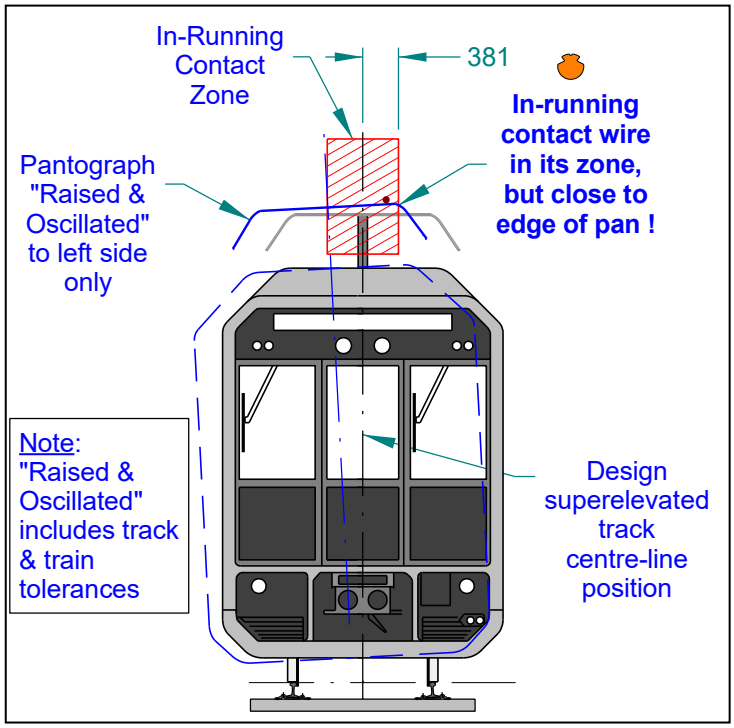

In-Running Contact Zone
381
In-running contact wire in its zone, but close to edge of pan !
Pantograph "Raised & Oscillated" to left side only
Note: "Raised & Oscillated" includes track & train tolerances
Design superelevated track centre-line position

Figure 30 - Pantograph with all Track & Train tolerances applied to left side only

Refer back to *Figure 27* for a diagram showing the 3 track tolerances (position errors), which should give a better appreciation of the track movement issue faced here.

In relation to the contact height – aspects a) and b) above – other requirements also come into play to help ensure reliable and uninterrupted electrical supply to the train, especially

with the train travelling at higher speeds. Included in this is the provision of suitable contact wire *ramp rate*, which is a measure of how quickly this wire ramps up or down in a bay, *relative to the track*. This height change requires limiting due to the inertia of a pantograph and its ability to change heights quickly. (Older pantographs were heavier and less able to trace the contact wire under more abrupt height excursions.) Otherwise significant arcing from pantograph to contact wire may result.

The ramp rate should not be steeper than typically 1:300 for fixed-anchored OHW and 1:500 for regulated OHW (although this may have changed recently and may be speed dependent too). For example, in a 50m bay of fixed-anchored wiring, the maximum ramp should be 166mm from one end of bay to the other – say 5.0m at one end of the bay down to 4.834m at the other end (for possibly then going under an overline bridge).

Refer to the standards for the current applicable contact ramp rates.

Also, the travelling pantograph shouldn't experience any abrupt changes in the level contact (e.g. *kinks* in the contact wire) that could otherwise cause arcing and possible power loss to the train at that point.

Note that the in-running contact red zone, and particularly its lateral width, is very small compared to the train and its pantograph. Keeping within this red zone is probably the most important challenge facing OHW design engineers on any project. This is one important reason why the OHW needs to be built according to the design, and any deviations outside the stipulated tolerances need to be checked out, with either the OHW corrected in the field (preferred) or the design altering to suit (if the difference is checked out OK).

It's relatively easy to correctly stagger the contact wire at a support location in a position that achieves pantograph security. For example, 250mm stagger relative to the superelevated track. The Track Control Marks (TCMs) installed on all OHW structures help the track maintainers to keep track of their track (so to speak). They capture 3 *design* values: the horizontal offset from TCM to the track, the (low) rail level and the track superelevation.

However, what's much more difficult is to make sure that the contact wire is within its horizontal limits on *existing* track *throughout the rest of the bay*, especially when some of the bays can be 67m or more in length. The existing track geometry can be an issue, and unfortunately there are usually no convenient TCMs at or near mid-bay for ready reference. And the amount of blowout under 130km/h wind speeds throughout this long bay adds another dimension to this in-field problem.

The designed position of track needs to be taken into account in the OHW design, and it's the reason why the track has to be maintained within stipulated *tolerances* of its design position (especially regarding its lateral and superelevated positions *through the bay*). A track *transitioning* from one radius to another over a distance introduces another challenge in this regard.

This requirement for *pantograph security* (with high wind speeds) is instilled in the OHW design if properly done, but it is sometimes difficult to convince others of its importance. I know there have been a number of times when people were surprised (and even suspicious) that there was such little room for the in-running contact wire to be located [i.e. dimension (c) above]. The attitude has often been that the OHW "just needs to be somewhere above the train, to do its job". Of course, this attitude is wrong. In the end, the pantograph security argument should take priority over any other personal attitudes. For more details regarding Pantograph Security, refer to *Section 6.3.2.2*.

2.8 UNOBSTRUCTED PANTOGRAPH PATH

There must be no obstructions in the path of a train's several pantographs. If something strikes a pantograph or otherwise interferes with its passage, this jeopardises the pantograph, the OHW and/or nearby infrastructure, and can ultimately affect train operations. Normally, damage from such an event can take many hours or even days to repair.

So, while the contact wire is allowing the pantograph to glide along it in a smooth way, the remainder of the OHW system (components) must be kept out of the path of the pantograph's operating envelope. This is essential even under the extreme conditions, including high wind speeds and hot & cold temperatures, etc.

Of course, things like fallen trees onto the OHW or objects blown into the OHW, etc. are unpredictable external events that can lead to the same service disruptions.

Parts of the "live" OHW system (at 1500V) can approach a *mechanical clearance* distance of the pantograph, e.g. the *heel* of a pull-off arm, as shown in *Figure 31*. However, all parts of surrounding infrastructure, that are at or close to earth potential, need to remain well clear under the worst case (closest) situation. This normally involves having an *electrical clearance* of 150mm superimposed onto the mechanical clearance profile, and this distance is to the pantograph in its closest diagonal position to the object.

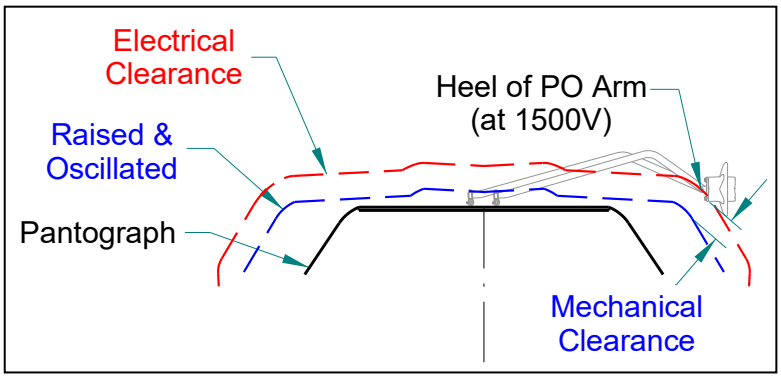


Figure 31 - Pantograph Gauge

A *Pantograph Gauge* (*Figure 31*) is often used to assess situations for adequate clearances. This gauge shows both the above clearance envelopes – mechanical (in blue) and electrical (in red) – based on some *average* pantograph shape (in black), and with the pantograph at its worst position (which is affected by contact height). For more details see *Section 6.3.2.3* and *Section 6.3.2.4*.

It might seem obvious, but it's important to understand that
the contact wire controls the pantograph height.

So, the contact wire can have a big impact on pantograph clearances to nearby objects. This can happen, for instance, when raising the contact height through a railway station (maybe in sympathy with proposed track lifts). This seems harmless enough. But if the OHW is fixed-anchored, under cold temperatures its mid-bay height can rise up to 300mm (dragged up by the reduced catenary sag), and this may actually cause the edge of passing pantographs to come closer to any station awnings located out in vertical alignment with the platform edge, possibly infringing the required electrical clearance, or they may even strike the awning.

This scenario was about to happen at Central Station Suburban Platforms about 20 years ago. The proposed track lifts at the time meant the already low OHW had to be raised, but a higher contact wire reduced the diagonal clearance from pantograph to the station awnings, which were very close anyway. Refer to *Section 6.4.6.1* for further details of this specific issue and how it was resolved.

At times there have been rather strange situations with the way the OHW was configured, that caused unforeseen problems. Such a situation happened with badly adjusted old fixed-anchored OHW a few years ago, where every now and then (only when it was extremely hot and with trains drawing lots of current) a certain contact clamp in the out-of-running contact wire would lower down into the path of a train's pantographs and strike them, causing

damage to the pantographs' carbon strips. (The clamp had parts to it that hung below contact level but it was never meant to come anywhere near a passing pantograph for this reason.) When the OHW was slightly cooler, the clamp would retreat upwards and out of the way.

This situation was very difficult to fault find (taking days) as it didn't actually stop the affected train, and the damage was only noticed more than 100km away (at Mt Victoria I think). See *Section 4.1.1*, *Conductors* for more details on this one.

2.9 1500V INSULATION

Probably the two most important elements of an OHW system are the copper wires that supply power to trains, and the means for them to be situated in the air and to operate safely and reliably at 1500 volts – through *primary insulation*. So, it's worthwhile to mention some fundamental characteristics of insulators here.

More details of the various insulation materials used in OHW are given in *Section 5.1.16.2*.

There can be 3 *levels* of insulation applied within the OHW system, namely:

- ***Primary insulation*** (intended as the front line 1500V insulation, but capable of withstanding a much higher voltage).
- ***Secondary insulation*** (applied in addition to primary insulation, but intended for lower voltage levels, as used in bonding circuits).
- ***Tertiary insulation*** (applied in addition to secondary insulation in certain rarer situations).

For more details see *Section 3.12.0.5, Levels of Insulation*.

Note:

Although there are many *insulators* available to the electricity industry, Sydney's 1500V ***dc*** OHW system has its own special requirements that insulators need to meet.

Any proposal for a new type of insulator requires it to be *type tested* – at high voltage, but probably more critically at high dc current (read this as thousands of amps) with flashover tests. It takes time and money to properly evaluate and endorse any new insulators for suitability, so as to maintain the high levels of *reliability* that are currently in place. There are also other design aspects that need to be evaluated, such as suitability with other OHW hardware, interchangeability, etc.

Ultimately, they must be approved for use by the Standards group in the organisation.

The OHW conductors are operated at 1500V, so these wires must be regularly supported and the wire runs eventually anchored at both ends using special 1500V *primary insulators*. They are rated for much higher voltages – the extra insulation level is needed to cope with adverse situations, including periods of heavy rainfall and (to a degree) voltage surges from lightning.

Also, there seem to be 3 main OHW situations where 1500V insulation is required. They are based on the applied *mechanical loading*, and the chosen insulators need to be capable of reliably holding those mechanical loads over time. These insulator loads are:

a) ***Full in-line conductor tension***. This is the highest loaded situation, and includes catenary and contact termination insulators at anchors and at section insulators. E.g. anchoring 30kN (3 tonnes) catenary tension. See *Figure 32*.

b) Under some ***support load***. This is an order of magnitude lower than *in-line tension* above, and employed at the various support & registration locations. It includes the weight loads of a bay of OHW, and radial loads as the catenary and contact wires change direction at

each staggered registration location in a wire run. The insulation has to withstand this degree of mechanical loading, and it includes wind loading on the wires too. E.g. 3kN weight load (vertical); or 2kN radial load + 1.2kN wind load (lateral). See *Figure 35*.

c) With ***low load***. This can be yet another order of magnitude lower than the *support* loads above. For instance, the insulation needed to isolate rail potential from earth, often simply supporting the weight of a piece of equipment (and often spread over a number of support insulators). E.g. The rail-connect terminal of an old Railway 1500V switch on a mast.

A few of the standard insulators can handle all above 3 scenarios. However, insulation designed only for (b) above should never be used in situation (a) – you get the idea.

The loads on most insulators are typically tensile, but they can sometimes also be compressive, and with bending or even twisting in nature. See *Section 3.2.0.5, Mechanical Strength* for more details.

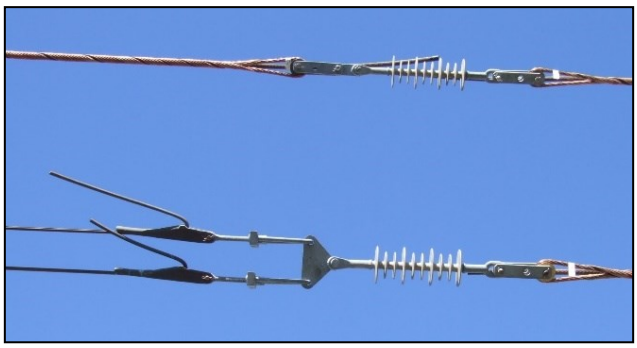


Figure 32 - "*K-Line*" Fibreglass Insulators

The 1500V insulators normally include *skirts*, which appear as corrugations. These increase the surface path across the insulation from one metal end of insulator to the other. *Figure 33* shows what these look like.

Figure 34 has a cross-sectional part-view of the insulation including the approximate shape of the skirts. The creepage distance is shown as a thick red line, from metal cap to metal tongue.

Insulator skirts are an effective mechanism to help the energized OHW cope with heavy rainfall without causing flashover, and they minimise any dc leakage currents across the surface (provided the skirts are able to effectively shed the water).

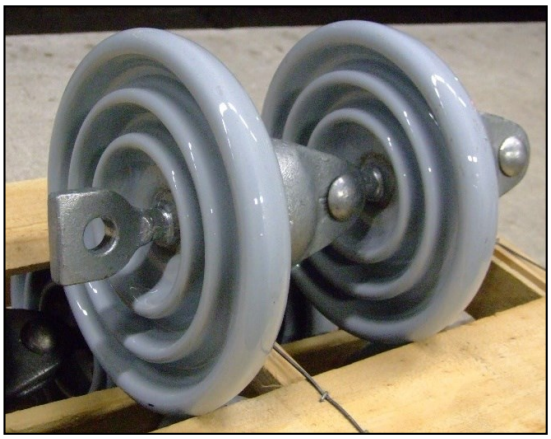


Figure 33 - Suspension Insulators showing corregated skirts

If areas of the insulation surface become polluted, this extended path again helps to minimise any leakage currents.

Ideally each insulator should be installed with corrugations located underneath, so when it rains, there are areas of dry surface near the peak of the corrugations. But this orientation is not always possible.

Figure 36 shows a situation where the corrugations are located on the right-hand side of the post type insulators (unfortunately out of view). Even in this situation they ultimately help deal with the water.

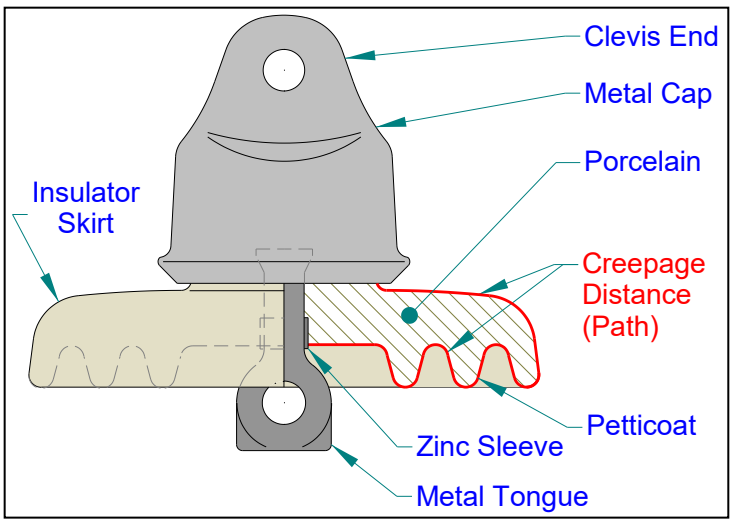


Figure 34 - Insulator skirts & creepage distance

Where 2 (or more) insulators need to be joined together to improve the voltage rating, Sydney had a long time ago standardised on the use of *tongue & clevis* connections at each end of the insulator, so they can be added in series and joined by a 16mm or 19mm diameter galvanised steel or stainless steel pin. (An alternative was *ball & socket* connections, which are used by other supply authorities.)

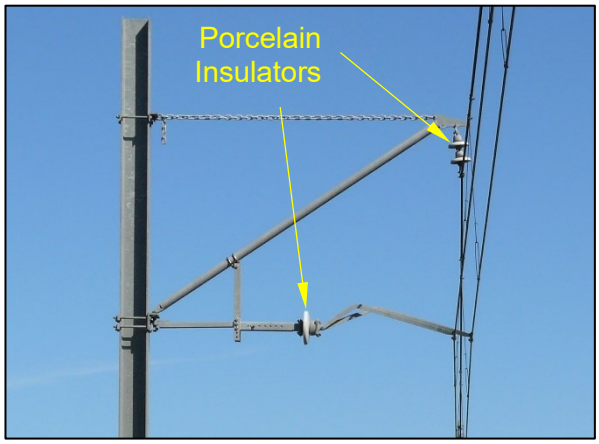


Figure 35 - Porcelain Insulators on a typical Cantilever

The pair of catenary suspension insulators shown in *Figure 33* and *Figure 35* are joined by tongue & clevis – the steel tongue is on the underside of each insulator and the steel clevis (with 2 sides) is on the top and is part of the insulator's cast steel cap. A standard 16mm stainless steel pin makes the connection here. (The 19mm pin is used for the larger termination insulators.)

With all types of insulators, pollution build-up on the insulation surface can cause current leakage / tracking problems. This can be a particular problem inside long tunnels where rainfall is prevented (which could otherwise help wash off some of the surface pollution).

These days 1500V insulators are normally made using one of 3 insulation technologies:

- Porcelain (*Figure 35*).
- Fibreglass Rod (*Figure 32*).
- Cycloaliphatic Resin (*Figure 36*).

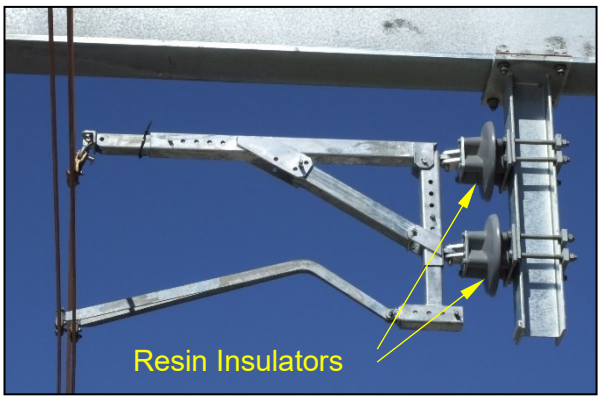


Figure 36 - Resin Post Type Insulators

Surprisingly, some insulation is used in the OHW system that isn't rated for the full 1500V. It's there simply to prevent dc current flowing through certain parts, which would otherwise lead to some detrimental effect on the equipment. In such a situation, both sides of the insulation material are at 1500V, so there is virtually no potential difference across it, but it blocks any small dc leakage currents that may otherwise flow from one part to the next.

An example occurs in cross-span wire, which is held up at certain points by vertical hangers from the catenary wire above. To prevent current flowing through these hangers, *loop strain* insulators are installed in line. Also, nylon *insulated sleeve* are installed in 2-part droppers these days to prevent micro-arcing at the sliding connection point, when uplifting pantographs pass by. In both these cases the absence of the insulation can eventually lead to premature failure of the equipment over time caused by even small current flowing through the connection.

Included in the list of insulation materials for preventing *leakage* currents (in somewhat chronological order) is:

- *Permali*, e.g. used in some older section insulators (although in some situations this material is required to be stressed at 1500V).
- *Fibreglass sheet*, e.g. catenary clamps installed and insulated on L-Irons in some older overline bridge arrangements.

- *Tufnol* – multiple layers of cotton, impregnated in resin under pressure, e.g. used for insulating horizontal safety screens from bridges, etc.
- *Acetal resin*, e.g. *Delrin* as used in a twin-contact *Delrin Bar* dropper arrangement.
- *Nylon*, e.g. as used in insulated clip-on dropper sleeves.

Because the 1500V insulators are fundamental to the operation of the OHW, and they are referred to extensively through the remainder of this document, I have added more information about each technology below (at this early stage in the document). As mentioned above, more details may be found in *Section 5.1.16.2*.

Refer to the following Standards:

- EP-08000019-SP, "Performance Specification for Overhead Wiring Post Type Insulator Units".
- EP-08000020-SP, "Performance Specification for Overhead Wiring String Insulator Set".
- EP-08000021-SP, "Insulator Type Tests – DC Power Arc Withstanding".

2.9.1 Porcelain

This is the oldest technology and is still in use today (although not as commonly used now).

The porcelain insulation is typically used in conjunction with a cast steel cap (galvanised) at one end, and a steel tongue at the other end (which is galvanised and includes a zinc sleeve, and I understand some tongues were made from stainless steel). *Post type*, *suspension* and *side strain* insulators often have this type of insulation. See *Figure 33* and *Figure 35*.

The older *loop strain* insulators are solid porcelain with no metal parts at all – *Figure 37*. They rely on wire passing through a hole in the insulator, then looping back and terminated with U-bolt clamps, and another wire coming from the opposite direction doing likewise, but its hole is located beyond the first hole and is rotated 90° from the first. It is this rotation that provides the 2 wires with the needed electrical clearance and isolation, but provides a fairly limited creepage path. The applied tension in the wires places the central portion of porcelain in compression, giving the insulator relatively high strength in this situation.

Figure 37 - Old Loop Strain Insulator

Note that porcelain is not so good in tension, and even the common suspension insulator in *Figure 34* has a wedge shape at the top of the tongue (shown) that places the porcelain in compression (not in tension as one would think at first glance).

Two such loop strain insulators are placed in series if used to hold catenary tension, although the population of such arrangements is small and diminishing as newer insulators are now preferred. (Refer to *Figure 395* further on for an instance). A smaller version is used to support a cross-span at a certain height (see *Figure 185* further on for example).

For the first 3 types of insulators, the metal cap and tongue are intended for pin or bolted connection to other support components (support brackets, additional insulators, links, suspension envelopes, pull-off arms, etc.).

Unfortunately, the relatively small diameter of the tongue (about 13mm or 19mm) can be susceptible to corrosion from *dc leakage currents*, and so some form of sacrificial protection (zinc sleeve) is typically employed. Because of this problem, ideally the tongue should be oriented on the "dead" (or negative potential) side of the equipment – but this cannot always be achieved for other important reasons. E.g. see catenary suspension insulator pair in *Figure 35* which have the tongues on the "live" side (not so good), but the pull-off insulator has its

equivalent post type insulator tongue on the dead side (which is good). For more information on this refer to *Section 5.1.11*.

Depending on their mechanical strength, they can be used with virtually all forms of OHW loading situations: anchoring full tension, and providing catenary support and contact registration.

2.9.2 Fibreglass Rod

These insulators usually appear as long rods, such as that shown in *Figure 32*.

Internally, their strength comes from a multitude of fine strands of glass, oriented lengthwise in line with the applied tension, and impregnated with resin.

The outside of the insulator is sealed to prevent moisture ingress into the fibreglass. Without this seal, moisture can apparently wick along the fibreglass strands and dramatically reduce the electrical insulation properties.

The outer layer is either varnished (older approach) or it has some form of silicone rubber covering to effectively prevent moisture ingress. They usually (but not always) include an insulator skirt to achieve greater surface creepage distance, which minimises leakage currents and may improve lightning flashover performance.

Fibreglass insulators have exceptional tensile strength but *almost no compressive or torsional strength*. So, both the application designer and installer should ensure that these insulators are never installed in a way that can lead to any significant compression or torsion loads, even if temporarily applied (during construction).

Some big benefits of fibreglass are that they are:

- relatively light in weight, and
- because of their longer length, they can provide greater insulation levels (contrasted with heavier porcelain insulators which typically require 2 in series for similar insulation levels, e.g. when anchoring the conductor tension). But this longer length can sometimes prove a problem in tight situations.

For support & registration, fibreglass rods are only sometimes used in tunnels as insulated pull-off arms (because of the limited clearance room preventing the use of other types of insulators).

Example: Pull-off arm fitting 354/64, and fitting 246/14 used in Coalcliff Tunnel.

However, these insulators are much more commonly used to terminate the highly tensioned catenary and contact wires at anchors, pennant insulators and section insulators. This usually achieves a good outcome.

Currently only the *K-Line* insulator (453/16) and *Reliable* insulator (453/17) are fibreglass insulators approved for holding in-line conductor tensions in the network (and have been since the 1980s or 90s).

2.9.3 Cycloaliphatic Resin

Recent advances in materials have enabled porcelain to be replaced by a superior plastic resin in most circumstances. Refer to *Figure 36* for instance.

Insulators made from this new material rely on a large volume of the resin to achieve exceptional tensile, compressive, bending and torsional strengths. Initial indications from the manufacturer suggested that their immense strength actually increases with age (which is

somewhat hard to believe).

This material has been used throughout the electrified network in post type insulators (fitting 452/10 as shown in the above figure) since the 1990s, with no significant issues to date, apart from some initial manufacturing design issues which were immediately addressed. Refer to *Figure 268* for instance.

Cycloaliphatic resin insulators have been used in pull-off registrations, catenary supports under bridges and in tunnel cantilever installations (*Figure 36*). Smaller insulators have been used in insulated knuckle arrangements (such as that shown in *Figure 118* and *Figure 119*).

2.9.4 Permali

Permali is a timber-based product, somewhat like plywood in makeup. But the selection of a strong hardwood timber species, the multiple cross-lamination structure and the way it has been impregnated with resin, combine to make it strong, durable, dimensionally stable and a relatively robust material with good insulation properties for certain OHW situations.

It has found use in a few places that would otherwise have been difficult to solve with other materials available in the old days. Examples include:

- Insulated contact knuckles (see *Section 3.1.5.4*, *Insulated Knuckle*),
- Main insulation beam in some section insulators (Type 5 and BICC – *Figure 397*), and
- Rail-connect terminal insulation pad on some old switches (left side of *Figure 430*, etc.

To prevent moisture ingress and consequent reduction of electrical insulation properties, the material needs to be initially sealed, e.g. by varnishing or painting all surfaces (even bolt holes). Like the fibreglass insulators (above), any moisture finding its way inside can gradually wick to both ends and cause current leakage problems. Over its lifetime it may need to be further resealed to help keep it in good condition.

Refer to *Figure 400* much further on for a permali beam that had failed. It has an end view revealing the levels of timber laminations that help give it the incredible mechanical strength it has.

2.10 TWO IMPORTANT OHW ASPECTS

There are 2 main aspects that require an ingrained understanding by those people involved in design, construction or maintenance of the OHW, who are in a position called on to change any part of it. More information is detailed later, but I felt it important to state these here.

IT'S ALL ABOUT THE CONTACT WIRE

As discussed in *Section 2.4* and *Section 2.7*, there needs to be an awareness of the requirement to keep the in-running contact wire in a position such that it *always controls the train's several pantographs*, even with 130km/h crosswinds and even if the train is travelling at similar speeds. This aspect is termed *Pantograph Security* for obvious reasons (and discussed in many later sections, but primarily *Section 6.3.2.2*).

Just about every part of the OHW infrastructure is there to help the contact wire to smoothly connect with the train's pantographs, and reliably feed high magnitude electric current (up to a few thousand amps) to the train, at about 1500 volts.

So, it's not just the contact wire's condition that's important; its relative location (to the track being serviced) is also of paramount importance, and this needs to be fully understood, respected and ultimately maintained in the field, into the future.

"FIXED-ANCHORED" IS NOT "REGULATED" OHW

These 2 methods of tensioning the catenary and contact wires were introduced in *Section 2.5.3*, and are covered in much more detail in *Section 3.1.0.4*. Both ways of tensioning the OHW conductor runs are valid for different reasons.

The point I make here though, is that most workers who grew up knowing only fixed-anchored OHW have now retired – it used to be installed everywhere. These workers were quite aware of its various quirks, and consequently knew how to effectively deal with them in order to achieve a relatively simple but reasonably reliable train interface.

However, probably something like 80% of OHW construction work now deals with regulated OHW – in new construction, upgrading works, etc. So, workers are currently quite familiar with (and trained in) the almost ideal tensioning character of regulated OHW, and the quality of workmanship is consequently quite good.

But as a consequence, these days workers tend to think that *all* OHW behaves the same way (i.e. like regulated OHW). Therefore, the remaining 20% or so of work performed on fixed-anchored OHW can suffer if people do not appreciate its unique character and work to it. After all, there are large areas of fixed-anchored OHW throughout the network, and recent new routes (mostly in tunnels) were, I think, quite rightly still being built with it.

There have been a number of incidents in the recent years that were caused by people adjusting fixed-anchored OHW inappropriately (some of it was design related). The mistakes should have been obvious, but no one noticed nor corrected the situation, until disaster struck.

This should be a significant concern for Sydney's train system, because the introduced problems may remain hidden for years and only make themselves known under certain extreme temperature conditions, which can make them extremely difficult to find until it's too late. The consequences on system reliability can be somewhat unpredictable and dramatic. For an example, refer to *Section 4.1.0*, headed "Problem Example". See also *Section 5.5.2.6*.

Clearly, people who design, construct, maintain or operate any *fixed-anchored* OHW need to understand its nature. And importantly, any training for newcomers should include this in the training syllabus, as it's likely the most effective way of instilling this knowledge these days. Some hands-on experience is also essential.

3 OHW Equipment & Components

This is by far the largest chapter, as it describes in detail the main OHW equipment and corresponding components. They are grouped into the following equipment categories (as shown on the front cover, which is repeated in *Figure 12* and listed in *Table 3*):

3.1 Conductors

3.2 Support & Registration

3.3 Support Structures

3.4 Anchors

3.5 Overlaps

3.6 Section Insulators

3.7 Switches

3.8 Feeding

3.9 Surge Protection

3.10 Over-Run Protection

3.11 Signs

3.12 (Bonding)

Within each of these sections, there's an initial *General* subsection, which is intended to introduce the equipment in generic terms. Then the various prime equipment and components are described using the following 7 aspect headings:

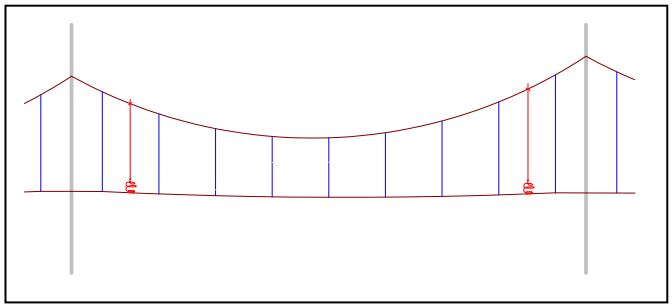
1. Description	Basic physical description of the equipment.
2. Function	What does the equipment do – why does it exist?
3. Typical Components	What are the basic components, including their "fitting numbers", etc.
4. Configuration	What does it look like, what are the variants and how does it behave?
5. Design Notes	Information of a design nature that may help gain a slightly deeper understanding of the equipment.
6. Status (c. 2014)	Are variants still used, and are there limitations on usage? (Status at 2014 only – see below).
7. Reference	Pointers to external documents that may add light to the subject, including standards, guidelines, publications, drawings, etc.

Notes:

Section 8, *Standards & Other Information* contains more details that may be of use, and particularly *Section 8.2* which lists all the relevant *Standard OHW Arrangements* generally for reference in future electrification works (or at least, as it existed in 2014).

Regarding *"6. Status"* (above) – The status of equipment types as at 2014 may change over time, so check the current Standards for the latest situation.

3.1 CONDUCTORS



3.1.0 General

3.1.0.1 Description

OHW conductors are usually copper wires and associated fittings that are located above, or sometimes near, a track being serviced. They are there to supply, or help to supply, heavy electric current at about 1500 volts dc (in Sydney), to a travelling train – this gives the train its immense available tractive and onboard power.

The main conductor wires – the *contact* and *catenary* wires – are regularly supported and registered at specified heights and horizontal offsets (*staggers*) from track, and they need to be kept within reasonably tight tolerances relative to the serviced track. These conductors are under considerable mechanical tension in order to help keep them in place (within limits) throughout each bay in a wire run, even under extremely windy conditions.

Refer to *Figure 39* for the boundary of what constitutes OHW conductors in a bay (shown with grey shading).

3.1.0.2 Function

OHW conductors serve as the front line electrical supply to electric trains.

They allow for the provision of a mechanically continuous *contact wire* path for a train's several pantographs to slide under, and in doing so, pass uninterrupted electrical current to these pantographs, often travelling at high speed.

In Sydney's 1500V dc electrical traction system, the amount of current fed to each pantograph is typically up to almost 1,000 amps, which is a huge amount (the whole train can demand more than 3,000 amps at times). I understand the newer Waratah trains can demand up to 3,600 amps for short periods, mostly during rapid acceleration. This, among other things, has placed an enormous burden on the OHW conductors, which need to be properly designed in order to reliably meet that demand and not overheat in the process. (Overheated conductors generally lead to failure of the OHW system, which stops trains.)

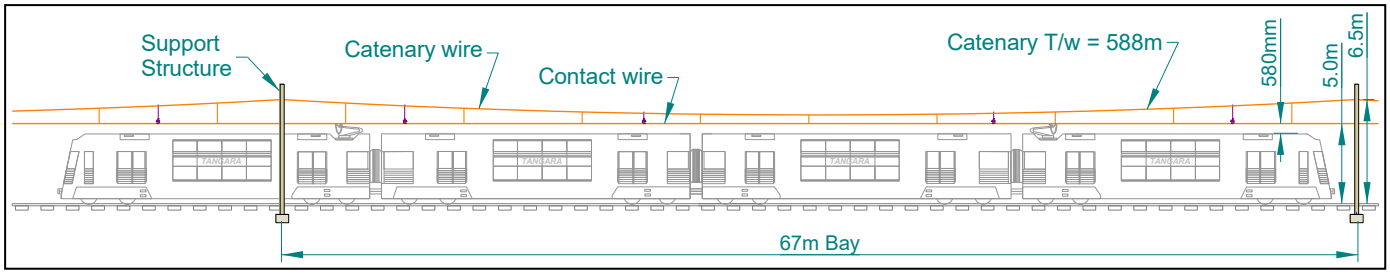


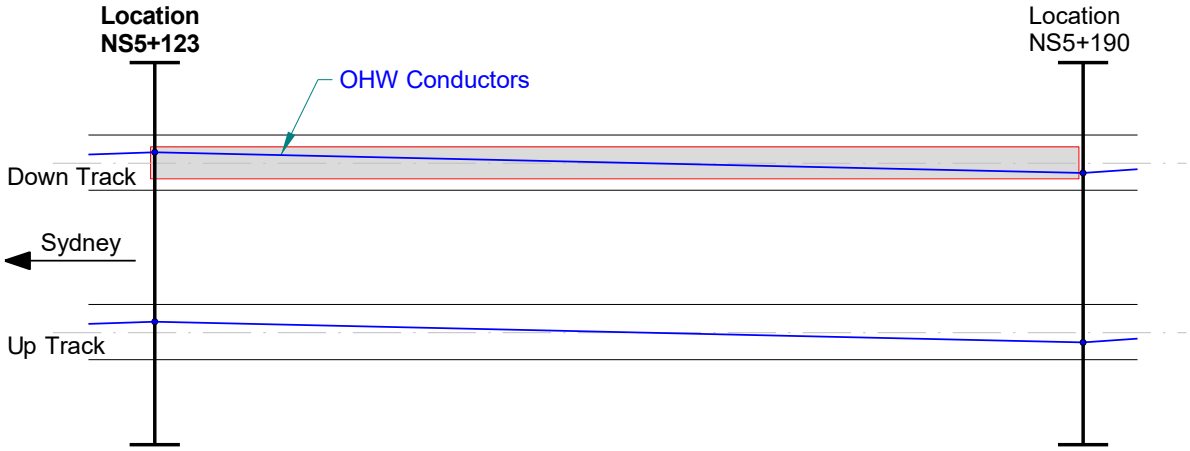
Figure 38 - Relative size of 4-car Train Set in a long 67m Bay of OHW

OHW Conductors

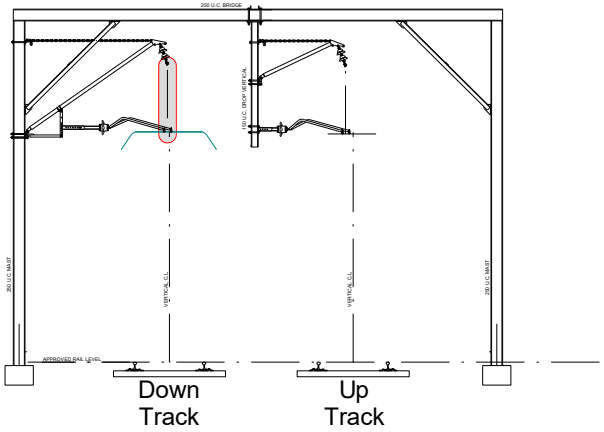
OHW Conductors

Asset in Bay
NS5+123, Down Track

Includes ...
- Catenary
- Contact
- Droppers
- In-Span Feeders
- Knuckles
- Contact Full & Half Splices
- Catenary Splices
- Pennant Insulators
- Contact To Contact Feeder Jumpers
- Catenary Feeder & Potential Jumpers
- Contact Wear Strips

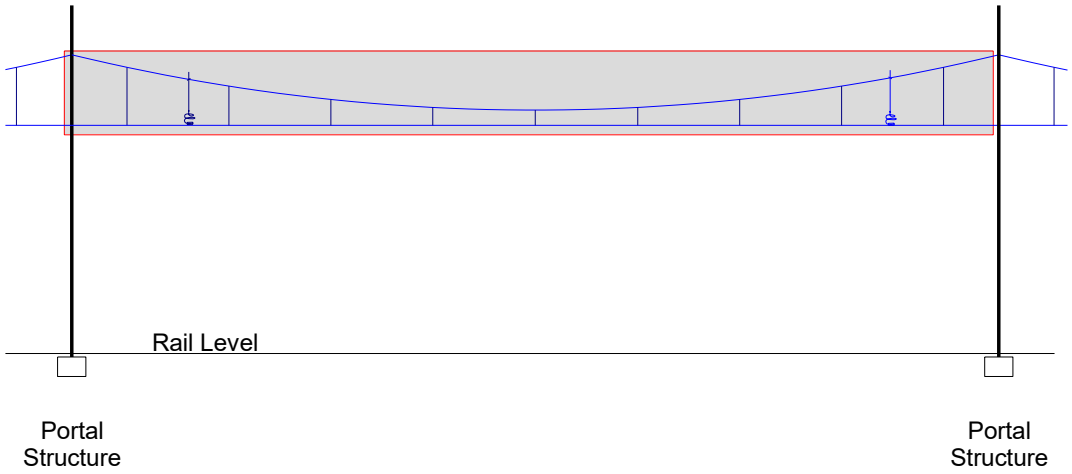


Top View



Location NS5+123

Left End View



Front View

Figure 39 - OHW Conductors - boundary

3.1.0.3 Typical Components

The main conductor component classes are listed below in *Table 5*, and each is covered in more detail in the corresponding Section.

Section	Conductor Component	Description
3.1.1	**Catenary Wire**	The upper wire that supports the contact wire, and in most cases helps feed current to the contact wire.
3.1.2	**Contact Wire**	The wire that a train's pantograph slides under to deliver the train's energy needs.
3.1.3	**Droppers**	Regularly spaced vertical lengths of copper wire that support the contact wire from the catenary wire above, and in doing so, give the contact wire its flat or near-flat shape relative to the track below (for good pantograph current collection).
3.1.4	**In-span Feeders**	Vertical lengths of multi-stranded copper wire incorporating a horizontal coil shape, that connect between catenary and contact wires, which in turn allows heavy electric current to flow (both ways) between these wires.
3.1.5	**Knuckles**	Mechanical devices that constrain 2 conductors together (catenary-to-catenary or contact-to-contact).
3.1.6	**Contact Termination Clamps**	Clamps that connect to the ends of the contact wire to grip this wire and allow it to transfer the huge applied mechanical tension in the wire to some other device (e.g. anchor).
3.1.7	**Contact Splices**	The "contact full-splice" is a joining device used for repairing the contact wire, which must also allow the pantograph to slide smoothly under it without arcing.
3.1.8	**Catenary Termination Clamps**	Devices that terminate a multi-stranded catenary wire and allow a huge mechanical tension to be applied to this wire e.g. at anchor locations.
3.1.9	**Catenary Splices**	These devices repair any damaged or broken catenary wire anywhere in a bay of OHW, allowing full tension to again be applied.
3.1.10	**Pennant Insulators**	Insulators used for the electrical sectioning (isolation) of catenary wires and/or contact wires in a bay.
3.1.11	**Contact-to-Contact Feeder Jumpers**	Devices that transfer heavy current from one contact wire to another (usually located close to where they come together above a crossover track).
3.1.12	**Catenary Feeder Jumpers & Potential Jumpers**	Devices that either allow heavy current to *feed* from one catenary wire to another (usually where they come close to or cross each other), or simply keep the catenaries at the same electrical *potential* (passing no current).
3.1.13	**Contact Wear Strips**	Sacrificial devices installed on contact wires that then prevent further mechanical wear on these wires (most commonly caused by pantographs "forking-in" at crossovers).

Table 5 - Conductor Components

The 2 main conductor components are the *contact* and *catenary* wires.

- The *contact* wire is highlighted in the above table because of its importance. This solid conductor is located about 5m above the track, but can go as low as about 4.65m in tunnels & bridges where there are restricted vertical clearances. It comes in direct physical contact with the train's pantographs, and thus supplies electric current directly to each pantograph. The contact wire is the main component, and it is the focal point of the OHW system – all other OHW equipment is there to get the contact wire in place so it can reliably supply the train. So, without the contact wire, there is no point to having the rest of the OHW equipment.
- The *catenary* wire (if used) is located vertically above the contact wire and directly supports it, while also helping to feed electric current to and from it. The catenary height is typically 6.5m above track at its support points, but can be up to about 7.5m. And it can be as low as 5.0m in tunnels and under bridges, when supporting a very low contact wire. But its height varies within each bay due to its parabolic shape as it sags under gravity between adjacent supports. The weight of the supported contact wire adds to the sag in the catenary wire.

A *bay* of OHW conductors is the length of these conductors from where they are supported to where they are again supported, as shown in the "Front View" in *Figure 39*. Typically, a bay can range from 30 metres or less, and up to 73 metres (but rarely more than this figure). These days, the maximum design bay length for OHW is 67 metres, and this would be on straight track. Shorter bays are normally required for tracks located on horizontal track curves, and the tighter the curve, the shorter the bay length, e.g. an 800m radius track curve will likely require bays to be limited to about 50m, and an extremely tight 200m radius track curve leads to 28m bays.

A *run* of OHW conductors is the length of conductors from where they are anchored to where they are again anchored. The wire run can be as little as 300 metres, or up to 2 kilometres or even more in length, depending on how it is tensioned. The run can comprise a large number of bays – commonly up to 30 bays for regulated wire, or as many as 50 bays or more in a fixed-anchored system. Most often, the catenary and contact wires both start at the same (or nearby) anchor location, and at the other end of the run they end at the same (or nearby) anchor location.

Table 6 lists the main conductors used by Sydney in the past, be they catenary wires or contact wires, or even "span wires" which belong to the next main section – "Support & Registration". Other conductors have been used in the past that are not in the table (because of their age or limited usage), e.g. the 61/0.105in copper "jumper" wire used in the Compound OHW system in the Blue Mountains. Also, some of the older conductors have changed in size marginally when they've been finally metricated. The following sections describe those conductors in current use for any new projects.

Most of the past, and all present OHW systems, are listed further on in *Table 7*, and they are categorised as either *regulated* systems or as *fixed-anchored* systems. I should point out that there may have been isolated areas of old OHW with unusual configurations that are not listed in the Table, but they are not important to mention here.

Size (mm²)	Strands (No. / mm)	Metal	Weight (N/m)	Dia-meter (mm)	Dyn. Wind Load (N/m)	Resistance (Ω/km)	Min Break Load (kN)	Modulus of Elasticity (Pa)	Alpha (per °C)
Stranded Conductors									
Catenary Wires									
165*	19 / 3.35	HD Cu	14.59	16.64	19.60	0.10952	65.0	124.0E+9	17.0E-6
179	19 / 3.48	HD Cu	15.98	17.40	20.40	0.09955	70.3	124.0E+9	17.0E-6
270*	37 / 3.05	HD Cu	23.97	21.34	25.00	0.06693	109.0	124.0E+9	17.0E-6
327	37 / 3.35	HD Cu	29.08	23.47	27.50	0.05540	128.2	124.0E+9	17.0E-6
510	37 / 4.19	HD Cu	45.31	29.34	34.30	0.03540	192.7	124.0E+9	17.0E-6
Others									
66	19 / 2.11	HD Cu	5.88	10.54	10.00	Unknown	26.2	118.0E+9	17.0E-6
90	91 / 1.12	HD Cu	8.10	12.34	14.44	0.20300	80.0	124.0E+9	17.0E-6
90*	37 / 1.75	Tin Cu	7.96	12.30	14.39	0.23700	44.9	117.0E+9	17.0E-6
90	37 / 1.75	Cad Cu	7.96	12.30	14.39	Unknown	49.0	117.0E+9	17.0E-6
91	7 / 4.06	Steel	7.03	12.19	14.26	2.10300	97.9	193.0E+9	11.5E-6
Solid Conductors									
Contact Wires									
137	N/A	Cad Cu	11.87	13.72	12.84	0.15400	56.1	117.0E+9	17.0E-6
137*	N/A	HD Cu	11.87	13.72	12.84	0.13180	46.5	124.0E+9	17.0E-6
137*	N/A	Tin Cu	11.87	13.72	12.84	0.15400	54.8	117.0E+9	17.0E-6
193	N/A	Cad Cu	16.89	16.41	15.36	0.10930	65.8	117.0E+9	17.0E-6
193*	N/A	HD Cu	16.89	16.41	15.36	0.09360	62.5	124.0E+9	17.0E-6
193*	N/A	Tin Cu	16.89	16.41	15.36	0.10930	65.8	117.0E+9	17.0E-6
* = Currently preferred conductors									

Table 6 - Various recent Conductors used in Sydney's OHW System

3.1.0.4 Configuration

The OHW can be categorised into two basic classes according to the means of tensioning the catenary and contact wires – *fixed-anchored* OHW and *regulated tension* OHW.

Although most of the parts are similar for both systems, their application can be quite different, e.g. vastly different spacing of the droppers throughout each bay.

FIXED-ANCHORED OHW

The catenary and contact wires for fixed-anchored OHW are simply and directly anchored at both ends of the wire run. These runs can be extremely long – I understand there were some run lengths of 3 or 4 kilometres or so in the old OHW. Refer to *Figure 41(a)*.

Sydney's initial OHW was all fixed-anchored, and this remained so up until the 1960s.

Fixed-anchored OHW results in tension variations in the conductors with any temperature change. Hot temperatures cause the copper wire to extend in length which consequently reduces its tension and thus increases the sag of the wire in each bay. The converse happens

with cold temperatures. For instance, a run of 1,000m of copper wire will extend by 170mm for a temperature change of 10C°. Refer to *Table 12* much further on. Note that this extension or contraction is not dependent on the wire's cross-sectional area.

The conductor heights at mid-bay are thus very much influenced by temperature, and this generally leads to relatively poor interaction with pantographs travelling at higher speeds when the wires are hot.

In spite of the above negative impression of fixed-anchored OHW, because of its simplicity, it can be used very effectively in *tunnel* situations where the temperature extremes aren't as great. And because the bay lengths here are necessarily much smaller for other reasons (typically only 30m or so), they allow better control of any change in sag due to temperature. So for instance, the ±300mm mid-bay contact excursions under temperature extremes shown back in *Figure 24* are likely to be only ±100mm or so, which is a good outcome. It's also an advantage that the train speeds are usually much lower inside tunnels, e.g. 80km/h maximum.

Inside a tunnel the hot temperatures can be less, due to lack of solar radiation heating the wires. And the cold temperatures generally aren't as severe, due to the thermal mass of a long tunnel and less outside influence, although the piston effect of the train passing through the tunnel does drag in the outside air to some degree (so to speak).

Fixed-anchored OHW can be a much simpler OHW system to build and operate since there's no special tension regulators to worry about. And, unlike regulated OHW (described below), the wires don't move longitudinally (in the direction along the track) with temperature.

Another apparent benefit is that run lengths can be much longer than for the regulated OHW counterpart. In theory they can be of unlimited length, using splices to join wires where needed. This can then result in fewer *overlaps* which would otherwise require additional OHW equipment (to be covered later in *Section 3.5*).

However, while it may seem to be desirable to have extremely long runs greater than say 4km, this can introduce problems later on when maintaining the OHW, or during incidents where the wire is damaged, since there's so much more length that is then affected. The extremely long runs also require more than 1 drum of wire to be used, so splicing the wires is required, and the splicing connections themselves (and in particular the contact full-splice) can have a detrimental effect on system reliability unless properly (continuously) maintained.

REGULATED TENSION OHW

With regulated tension OHW, the expansion and contraction of the copper catenary and contact wires with temperature is taken up by tension regulators, allowing the tension in the wires to remain relatively constant. Refer to *Figure 41(b)*, *(c)* & *(d)*.

Since the 1960s, progressively more OHW has either been installed as new regulated OHW, or upgraded from fixed-anchored to regulated OHW.

The most effective form of tension regulator comprises a simple set of weights installed beside a mast. These weights move down in hot conditions and up in cold conditions. In this way the tension, at least at the anchor, remains relatively constant. (Note that it may vary throughout the wire run due to "*Tension Loss*" – refer to *Section 3.4.0.5*, *Tension Loss*.)

The delivered tension is dictated by the number of standard cast iron weights multiplied by their individual mass, e.g. 40 weights × 25kg per weight = 1,000kg = 9.8kN, then a 3:1 pulley system further increases the tension 3-fold, delivering 29.4kN (about 3 tonnes) in this example. The mass of the weight support rod itself adds a little more tension to this.

The weights are about 320mm in diameter and, when combined together, they form a cylindrical stack that can be up to about 2m high (depending on the needed tension).

However, there's a compromise – the 3 pulleys cause the weight stack to travel 3 times the

amount that the wire extends or contracts, and this vertical movement needs to take place without interference with the ground below (when hot) or the pulleys above (when cold). So, the wire extension/contraction of 170mm per 10C° for a 1,000m wire run, becomes 3 times this amount = 510mm of weight travel per 10C°. See *Section 3.4* for further details on anchors.

Maintaining a constant tension in the *catenary wire* means its sag (under gravity) in each bay remains the same regardless of temperature changes, and this is highly desirable. A typical catenary sag for a 67m bay is 1m to 1.5m depending on its tension and weight (the higher the tension the less the sag). This constant tension, in turn, means that any tight clearances from catenary wire to any overline bridges located above it are kept at roughly that clearance, which is good. (With fixed-anchored OHW, these clearances become less under cold conditions which is often a concern, and this needs to be taken into account during its design.)

Maintaining a constant tension in the *contact wire* generally means this conductor behaves well under windy conditions (up to 130km/h winds), and its lateral "blowout" position on the train's pantographs is well controlled (i.e. within ±381mm from design superelevated centreline of track throughout the successive bays).

Because of the well-controlled blowout in a bay, keeping the contact tension constant can also allow longer bay lengths to be had. This can, in turn, reduce the number of support structures and associated equipment needed to support the OHW within the run, bringing economic advantages (in terms of both initial construction and ongoing maintenance costs).

Importantly, regulated tension enables the conductors to maintain their heights above track throughout each bay, irrespective of conductor temperature, and this leads to good pantograph interaction performance, which is especially important at high train speeds.

Lastly, the above nature of a regulated OHW system is such that it can pass *up to twice as much current* to supply nearby trains – this is discussed later in the document (e.g. *Section 3.1.0.5*, *Current Carrying Capacity*). This improved current rating of the OHW system may actually allow smaller wires to be used and at lower tensions, with consequent savings. And it can have other big benefits (also discussed later).

Gas tensioning devices, and even large springs, have also been used in the past to provide this regulated tension function, but neither of these devices are used any more. (The last remaining 6 gas tensioners, serving since the late 1970s, were removed from the Eastern Suburbs Railway line in 2010 – replaced by weight tensioners. The few spring tensioners that were installed elsewhere in the system are most likely all gone now too.) Both these devices had their own operational and/or maintenance problems, leading to their ultimate demise.

However, it should be noted that there are high-tech spring tensioners now available overseas that can deliver high mechanical tensions, and they show promising characteristics for use in situations where space is limited.

TENSION LENGTHS

A *tension length* is the length of a wire run that is effectively anchored at two end points, and in doing so, provides a common tensioning characteristic for that length of wire. Refer to *Figure 41* to see the various configurations of tension lengths for OHW.

Fixed-anchored wire runs are simply anchored at each end, so any local changes to the tension will affect the tension in the entire run (unless the catenary is rigidly held/fixed at certain locations, which alters their "Virtual Span"). And these tension lengths can run for a number of kilometres. Refer to *Figure 41(a)*.

Unfortunately, an early approach to running the fixed-anchored catenary and contact wires, was to allow them to part ways at various crossovers. For instance, the catenary wire continues along the main line while the contact wire branches off to service the crossover.

Although there were reasons for mixing wires, it made the situation much more complicated and the tension length of catenary and contact wire were then not the same.

This mixing of individual wires in wire runs can be seen in the 2 right-hand runs in *Figure 40* (at Redfern).

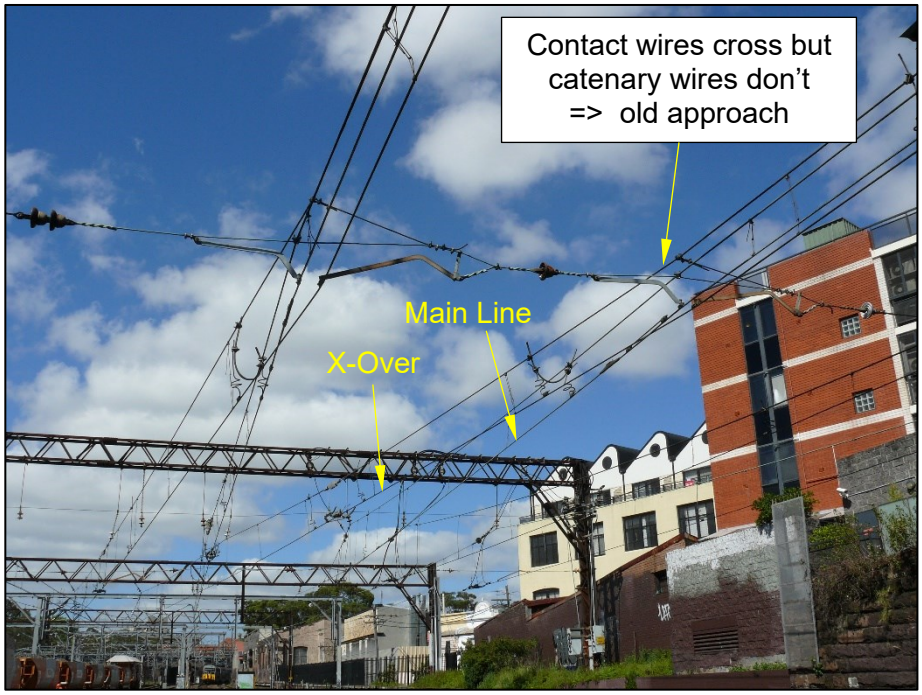


Figure 40 - Catenary & Contact Wires going their separate ways

However, I think it was more common to cross the catenaries and have the contact wires not cross, which then allowed for a flat-knuckled contact arrangement at diamond crossovers with low speed pantograph operation. For more on this approach, refer to *Section 3.1.5.5*, *Wires Parting Ways* and accompanying *Figure 120*.

Note that allowing the catenary and contact wires to part from each other has not been acceptable for quite a few decades now, and is virtually unworkable for any regulated OHW.

Unlike fixed-anchored wire runs, *regulated* wire runs are configured with either of the 2 below situations:

- A tension regulator installed at each end of the run, and a fixed mid-point anchor located somewhere in the middle. This is the most common configuration.
  So 1 run length = 2 tension lengths. Refer to *Figure 41(b)*.
- A tension regulator installed at one end and a fixed anchor at the other end.
  So 1 run length = 1 tension length. Refer to *Figure 41(c)* and *Figure 41(d)*.
  In terms of equipment used per kilometre, this approach is less efficient than the above approach (i.e. needing more overlaps, and the diagrams show this).

The maximum tension length for regulated OHW (from a fixed anchor to a tension regulator) is limited to about 1,000m. However, the actual tension length is site specific and depends on a number of factors, especially the track geometry (horizontal track curves, etc.) and the bay spacing between OHW supports (refer *Section 3.2.1*). Typically for regulated OHW, this translates to a limit of about 15 supports in a tension length, in accordance with the *Structure Spacing Chart*. Using more than this number of supports will likely cause unacceptable conductor tension deviations – termed *tension loss* – from the design tension – see *Section 3.4.0* for more details on tension loss.

In order to minimise the amount of OHW equipment, a normal run of regulated OHW comprises 2 tension lengths in the form of weight tensioners at the extreme ends of the run and a "fixed mid-point" (FMP) located somewhere near the middle (the first dot point above). In this configuration the run length can be up to about 2km (and possibly a little more if the right conditions have been designed into the run). As mentioned, tight track curves can reduce this figure dramatically.

ID No.	Location (where used)	Catenary		Aux. Catenary		Contact			System			Approx. Year Installed	Comments
		Size (mm²)	Tension (kN)	Size (mm²)	Tension (kN)	Size (mm²)	Tension (kN)	Metal	Tension Mode	Weight (N/m)	T/w (m)		
	Regulated Systems												
1	Gosford to Newcastle	**327**	16.50	-	-	**193**	16.50	HD Cu	Regulated	48.0	344	1982-84	
2	Waterfall to Pt Kembla	**270**	30.00	-	-	**2x137**	12.50	HD Cu	Regulated	51.0	588	1985	Standard twin-contact regulated system.
3	Liverpool to Glenlee	**270**	17.80	-	-	**2x137**	11.12	HD Cu	Regulated	51.0	349	1968	
4	Loftus to Waterfall	**270**	15.60	-	-	**193**	15.60	HD Cu	Regulated	42.0	371	1980	
5	ESR Viaducts	**270**	19.43	-	-	**2x137**	9.72	HD Cu	Regulated	51.0	381	1979	
6	Kingsgrove	**270**	19.00	-	-	**193**	16.00	HD Cu	Regulated	42.0	452	1991	
7	Metropolitan Upgrade	**510**	34.60	-	-	**193**	18.00	HD Cu	Regulated	62.9	550		
8	Metropolitan Upgrade	**327**	26.40	-	-	**193**	18.00	HD Cu	Regulated	48.0	550		
9	Metropolitan Upgrade	**270**	23.10	-	-	**193**	18.00	HD Cu	Regulated	42.0	550		Standard single-contact regulated system.
10	Metropolitan Upgrade	**165**	18.15	-	-	**193**	18.00	HD Cu	Regulated	33.0	550		Standard single-contact regulated system.
12	Metropolitan Upgrade	**2x270**	20.35	-	-	**2x137**	12.50	HD Cu	Regulated	74.0	550	1990	Twin-Caty/Twin-Contact regulated system.
15	Metropolitan Upgrade	**2x165**	15.40	-	-	**2x137**	12.50	HD Cu	Regulated	56.0	550	2006	Twin-Caty/Twin-Contact regulated system.
	Fixed Anchored Systems												
21	Metropolitan	**270**	15.90	-	-	**193**	13.35	Cad Cu	Fixed	42.0	379		
22	City Tunnels	**270**	14.15	-	-	**137**	9.34	Cad Cu	Fixed	37.1	381		
23	Hornsby to Gosford	**327**	17.92	-	-	**193**	13.35	Cad Cu	Fixed	47.0	381	1958	Mostly removed
24	Hornsby to Gosford	**510**	24.11	-	-	**193**	13.35	Cad Cu	Fixed	63.3	381	1958	Mostly removed
25	Metropolitan X-Overs	**165**	12.37	-	-	**193**	13.35	Cad Cu	Fixed	32.5	381		
26	Metropolitan X-Overs	**165**	10.99	-	-	**137**	12.46	Cad Cu	Fixed	28.8	382		
27	Penrith to Bowenfels	**327**	19.94	**179**	6.61	**193**	13.35	Cad Cu	Fixed	66.0	302	1957	
28	ESR Tunnels	**270**	19.43	-	-	**2x137**	9.35	Cad Cu	Fixed	51.0	381	1979	Eastern Suburbs Railway Tunnels
29	Tempe to Loftus	**270**	17.85	-	-	**2x137**	12.50	Cad Cu	Fixed	51.0	350	1990	

= Current OHW Systems for New Electrification Works

Note: Refer to *Table 6* for specific details of each conductor.

Table 7 - List of most past & present OHW Systems

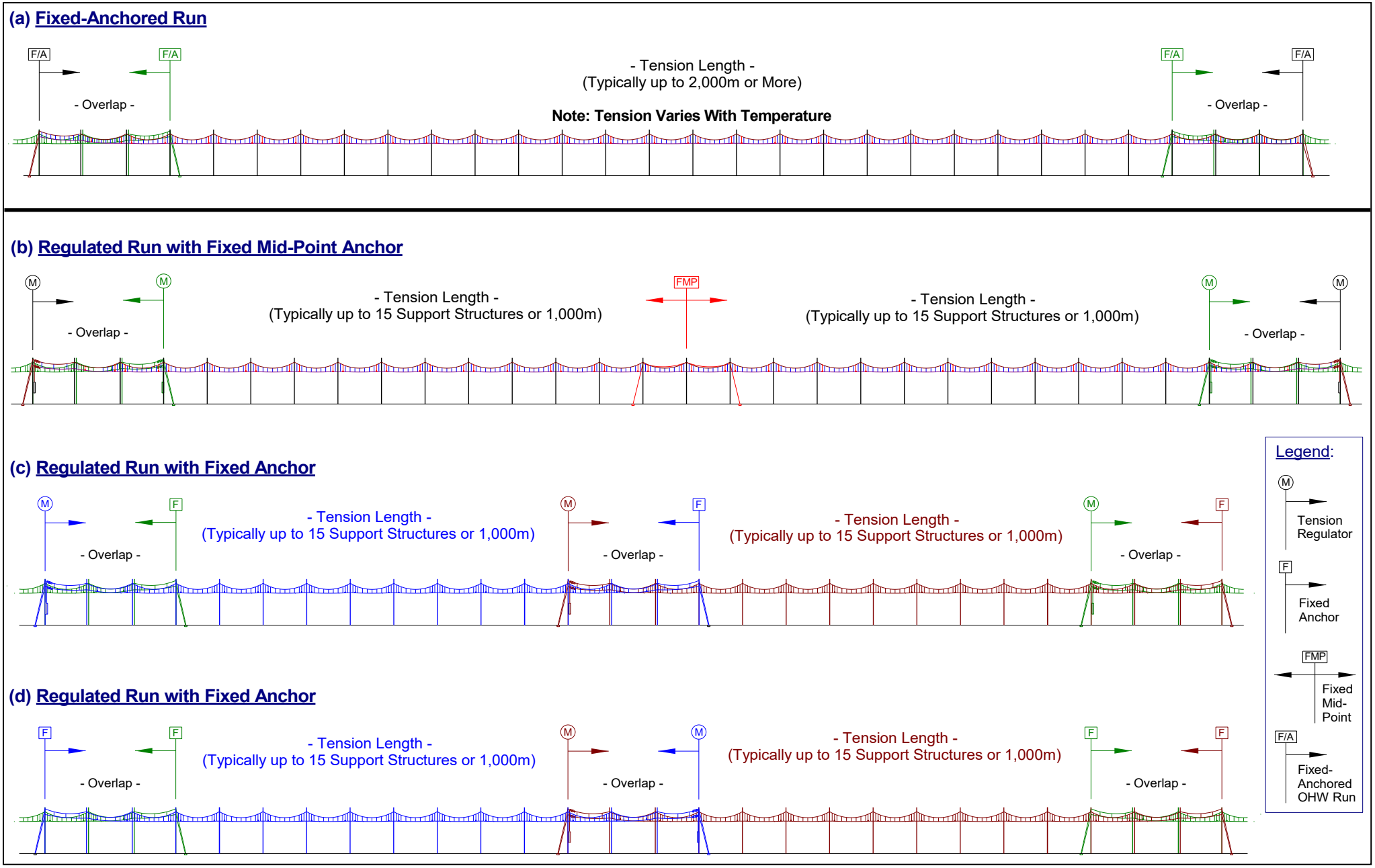


Figure 41 - Various Fixed-Anchored and Regulated OHW "Tension Length" Configurations

"FIXED-ANCHORED" VERSUS "REGULATED" OHW

From the above discussion, the benefits of regulated OHW are clear. The techniques required to achieve regulated OHW are generally quite straightforward. The equipment installed to regulate the OHW is also reasonably simple, provided the OHW is mostly located out in the open (it's quite a bit more complicated if located inside long tunnels). And simply regulating the OHW can sometimes almost double its current carrying capacity, compared to the fixed-anchored equivalent, as can be noted further on in *Table 8*.

The relatively moderate additional cost of regulating the OHW, compared to installing a fixed-anchored OHW system, is paid off many times over by the superior performance of the regulated OHW. This is in terms of tolerable pantograph speed, current carrying capacity, contact wire life, ongoing maintenance effort, etc. Refer back to *Table 4*.

An example of the savings:

> In the original Technical Maintenance Plan, the various runs of OHW were required to be closely examined by "hands-on" inspection (with power off) at least every 4 years if it's fixed-anchored, but this could be increased up to 8 years if it's regulated OHW. This laborious but necessary task can be quite expensive to carry out, requiring extended power outages above individual tracks. So performing it half as often should save a lot of money. And it should also deliver a better outcome, by being less boring to those given this highly repetitive task (which can, as a consequence, be prone to human error).

OVERHEAD WIRING CONFIGURATIONS

Variations exist in the way the OHW conductors can be configured, as detailed below, and as shown in *Figure 42*.

- ***Single Catenary / Single Contact***. This is the most fundamental OHW system, and is one that was extremely popular in the older fixed-anchored OHW. It's still used in regulated OHW systems too, where only medium current carrying capacity is required, e.g. for short crossover runs or sidings.
- ***Single Catenary / Twin Contact***. This is the "standard" OHW system configuration, providing a very high current carrying capacity. It was originally installed as fixed-anchored OHW, but is now predominantly regulated.
- ***Compound OHW***. This fixed-anchored OHW system comprises 1 catenary, 1 auxiliary catenary (located below the main catenary) & 1 contact wire. This system is only used on the Western Line, from Penrith to Lithgow – across the Blue Mountains. It is a relatively high current carrying capacity system as far as fixed-anchored wiring goes.
- ***Twin Catenary / Twin Contact***. This configuration is for regulated OHW only, and provides the highest current carrying capacity of all configurations (without introducing auxiliary feeders). It is very popular these days because of the extremely high current levels demanded from today's trains, e.g. this configuration was installed across the Sydney Harbour Bridge recently to replace the ageing fixed-anchored wiring.
- ***Contact Only***. Restricted for areas with slow speed traffic and where only a small current capacity is needed to supply the trains. For example, it's used over various tracks leading into a number of Country Platforms at Central Station (including the platforms). This configuration is unlikely to be used in future (except maybe for "Over-run Protection").

An additional catenary wire can be run near the catenary wire of the main OHW, and this is commonly referred to as an "*auxiliary feeder*". This approach puts "more copper in the air" and so enhances the current carrying capacity of the associated main OHW. There have been some situations that required 2 auxiliary feeders installed, e.g. at Wolli Creek Station on the Airport Line (refer to *Section 4.1.5*, *Support & Registration*).

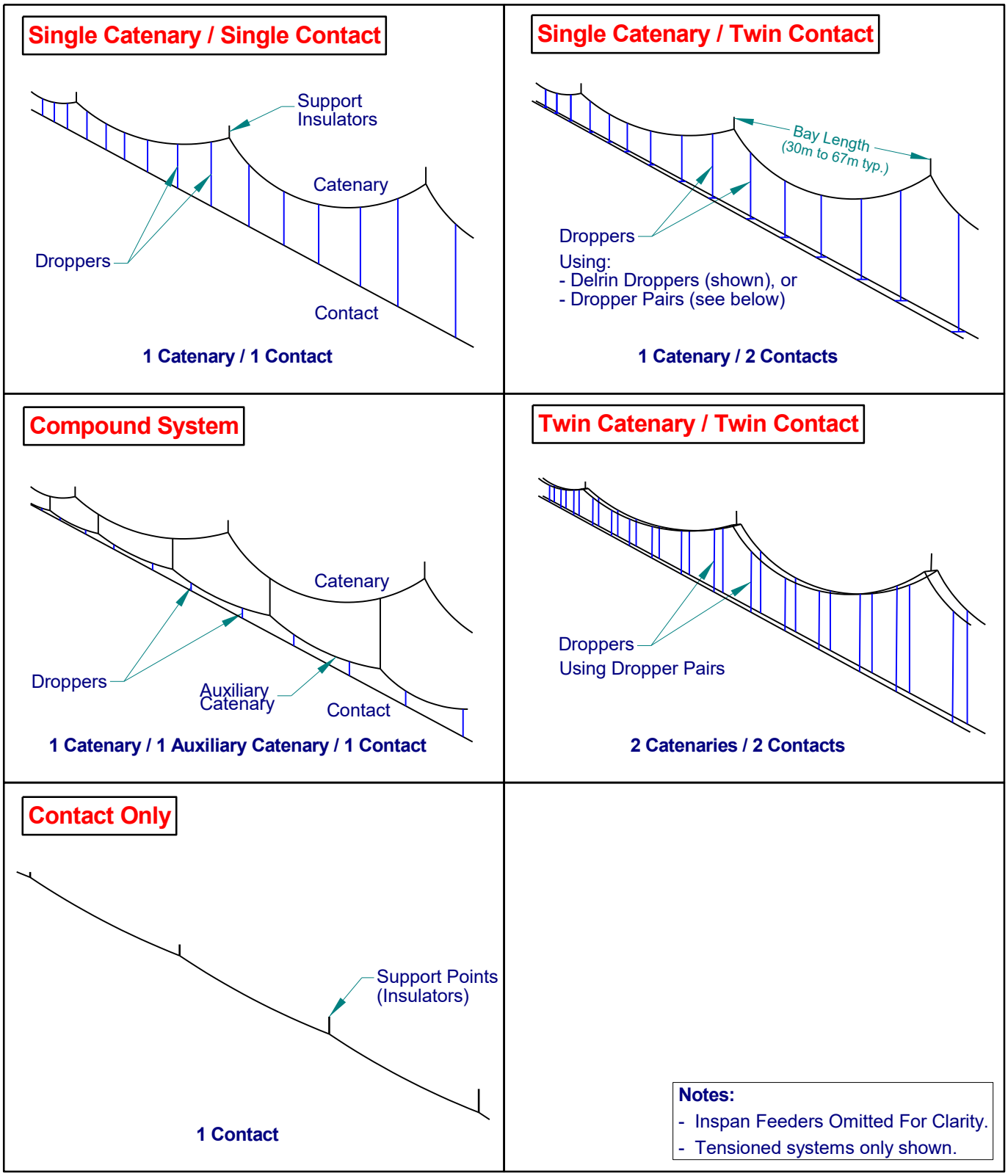


Figure 42 - Various OHW Conductor Configurations

The electrical current loading demand in the OHW over a particular track helps to determine the total amount of copper cross-sectional area (CSA) required in the OHW conductor system for that track. (The total CSA is the combined sum of all catenary and contact wire cross-sectional areas in parallel).

Higher electrical loads generally require a greater total copper CSA. This can lead to different numbers, sizes and combinations of catenary and contact wires used.

As mentioned above, regulating the OHW conductors can vastly improve the current rating, delivering more amps per mm² of copper CSA, compared to having the wire fixed-anchored. So, regulating the OHW allows the copper to be more efficiently and effectively used.

Electric current loading in the OHW is a function of:

- Train traffic density,
- Track gradients,
- Train mass,
- On-board train electrical loads, including lighting, air compressors, communications equipment, train control, air conditioning, etc.
- Regenerative braking, which pumps current back into the OHW to slow the train down. (This is on most suburban trains now.)

Currently there are 5 common copper catenary sizes and 2 contact sizes used in the electrified system, and the means of tensioning (i.e. regulated versus fixed-anchored) influences the final current rating of the OHW – see *Table 8*. (Note that there are a number of factors that go into the determination of the current rating of any particular OHW system.)

As previously mentioned, auxiliary feeders can be installed next to the main OHW as an add-on that can provide additional copper cross-sectional area in parallel with the existing main catenary/contact system, to help cater for higher load currents. Adding auxiliary feeders was fairly common practice in the old days. It was used in areas where increasingly heavy freight traffic needed to climb up steep track gradients. To a degree, the extent of auxiliary feeders can be as much as is needed to satisfy the demand (based on some load flow study of the area). Auxiliary feeders also lower the circuit resistance and can improve the electrical protection characteristics of that part of the line, which can be advantageous.

However, adding auxiliary feeders is not as popular these days because of safety concerns in some situations (covered later). Instead, a much better outcome is provided by installing a *twin catenary* system, if this is deemed practical. In this way, the OHW is more constrained to the track, and will act as a whole (rather than an independent auxiliary feeder which can take alternate routes away from the serviced track, which can then lead to problems).

For more on this, refer to *Section 3.1.0.5*, *Auxiliary Feeders* and *Section 3.1.1.5*, *Location of Auxiliary Feeders*.

EARLY ELECTRIFICATION

The early years of electrification employed simple fixed-anchored OHW schemes, and they mostly adopted a standard "*T/w*" of 381m (1,250ft).

The ***T/w*** (pronounced "tee on omega") defines the parabolic shape of the catenary wire, and is the catenary horizontal tension divided by the OHW system weight per metre (which is a representative figure that includes the weight of catenary, contact, droppers and in-span feeders). It is a measure of how much catenary sag will result in a bay of OHW – the higher the *T/w* number, the less the sag in the bay. The units are metres (or feet in the old days).

These days the standard *T/w* values for regulated OHW are:

- 588m – for the main single catenary / twin contact system, and
- 550m – for single contact systems and twin catenary systems.

Refer to *Figure 43* for a comparison of the sag depths of old (*T/w* = 381m) versus newer (*T/w* = 588m) OHW systems. (Note that the vertical scale is magnified 10x relative to horizontal scale.)

In the old days, adopting a standard *T/w* catenary shape for all OHW systems meant that the distributed dropper lengths (vertical distance from catenary to contact wire) in each bay could

be readily determined for any bay length, using a *dropper board*. A method of *dropper corrections* was available for unusual circumstances that didn't fit the norm. (There were no computers to do the calculations in the early days, until the late 1970s.)

Adopting the standard *T/w* also allowed for a standard set of plastic *sag curves* to be used in design work, that could easily draw the catenary profile in each bay of a wire run, which was extremely convenient and reasonably accurate too.

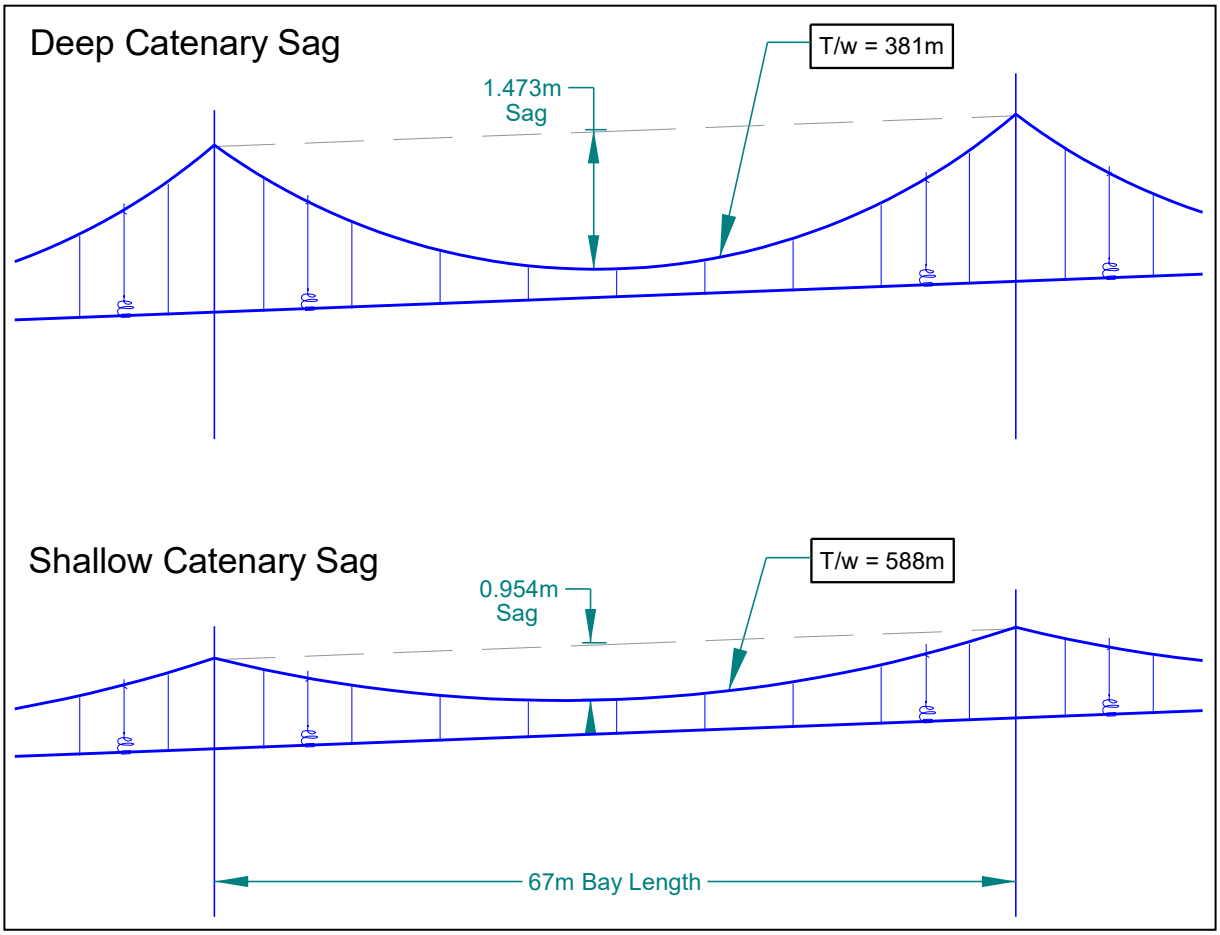


Figure 43 - Comparison of different Catenary "*T/w*" values

OHW System No.	OHW [Caty / Cont.] (mm²)	OHW Continuous Rating (Amps)	Current		Continuous Temp.		Copper Efficiency (Amps / mm²)
			Catenary (Amps)	Contact (Amps)	Catenary (°C)	Contact (°C)	
- Regulated Systems -							
12	**2x270 / 2x137**	**3,180**	**1,130**	**460**	**80****	**63**	**3.91**
15	**2x165 / 2x137**	**2,800**	**840**	**560**	**80****	**71**	**4.64**
7	510 / 193	2,100	1,663	437	80**	56	2.99
2	**270 / 2x137**	**2,050**	**1,130**	**460**	**80****	**63**	**3.77**
Test	165 / 2x137	1,960	840	560	80**	71	4.46
1, 8	327 / 193	1,880	1,276	604	80**	65**	3.62
4, 9	**270 / 193**	**1,780**	**1,132**	**648**	**80****	**65****	**3.84**
10	**165 / 193**	**1,560**	**840**	**720**	**80****	**76**	**4.36**
- Fixed-Anchored Systems -							
27#	327 / 179 / 193	1,770	906 / 497	367	62**	52	2.53
	327 / 179 / 193 (a)	1,440	737 / 404	299	62**	54	2.06
	327 / 179 / 193 (b)	1,940	992 / 545	403	62**	54	2.78
28	**270 / 2x137**	**1,530**	**901**	**314**	**66****	**53**	**2.81**
24	510 / 193	1,070	849	221	53**	47	1.52
22	270 / 137	1,000	741	259	59**	50	2.46
23	327 / 193	950	676	274	54**	48	1.83
21	270 / 193	875	587	288	54	49**	1.89

(Source: G. Hunter – 15/7/91) ** indicates limit.

Table 8 - OHW Current Ratings (mostly highest to lowest)

Notes for above Table:

- Ratings based on 39°C & 3.0m/s wind & 1,000W solar except:

  (a) 42°C / 2.0 / 1,000 for Penrith to Glenbrook (Lower Blue Mountains)
  (b) 35°C / 3.0 / 1,100 for Faulconbridge to Lithgow (Upper Blue Mountains)

- 25% contact wear. Emissivity = 0.7
- Regulated systems use hard-drawn copper contact wire; fixed-anchored systems use cadmium-copper or tin-bearing copper contact wire.
- # System 27 has Catenary (327mm²) / Aux Catenary (179mm²) / Contact (193mm²).
- OHW systems in bold are current systems for future works.
- OHW System with green background offers best copper efficiency.

The various *OHW system configurations* are shown below in *Table 9* for regulated OHW, and *Table 10* for fixed-anchored OHW.

TMP Code	Equipment Name	Made By	Drawing No.
EP-08-00-00-00	**1500V Overhead Wiring**		
EP-08-01-00-00	**Regulated - Single Contact OHW**	**RailCorp**	
EP-08-01-11-00	*510 Catenary, 193 Contact*		
EP-08-01-12-00	*327 Catenary, 193 Contact*		
EP-08-01-13-00	*270 Catenary, 193 Contact*		
EP-08-01-14-00	*165 Catenary, 193 Contact*		
EP-08-01-15-00	*510 Catenary, 137 Contact*		
EP-08-01-16-00	*327 Catenary, 137 Contact*		
EP-08-01-17-00	*270 Catenary, 137 Contact*		
EP-08-01-18-00	*165 Catenary, 137 Contact*		
EP-08-02-00-00	**Regulated - Twin Contact OHW**	**RailCorp**	
EP-08-02-11-00	*270 Catenary, 2x137 Contact*		
EP-08-03-00-00	**Regulated - Contact Only OHW**	**RailCorp**	
EP-08-03-11-00	*193 Contact*		
EP-08-03-12-00	*137 Contact*		
EP-08-04-00-00	**Regulated - Twin Catenary, Twin Contact OHW**	**RailCorp**	
EP-08-04-01-00	*2x270 Catenary, 2x137 Contact*		
EP-08-04-02-00	*2x270 Catenary, 2x193 Contact (e.g. Coalcliff Tunnel)*		
EP-08-04-03-00	*2x165 Catenary, 2x137 Contact (e.g. Sydney Harbour Bridge c.2010)*		

Table 9 - Regulated OHW Conductor Configurations

TMP Code	Equipment Name	Made By	Drawing No.
EP-08-06-00-00	**Fixed-Anchored - Single Contact**	**RailCorp**	
EP-08-06-11-00	*510 Catenary, 193 Contact*		
EP-08-06-12-00	*327 Catenary, 193 Contact*		
EP-08-06-13-00	*270 Catenary, 193 Contact*		
EP-08-06-14-00	*165 Catenary, 193 Contact*		
EP-08-06-15-00	*510 Catenary, 137 Contact*		
EP-08-06-16-00	*327 Catenary, 137 Contact*		
EP-08-06-17-00	*270 Catenary, 137 Contact*		
EP-08-06-18-00	*165 Catenary, 137 Contact*		
EP-08-06-31-00	**General Arrangement - Steel Catenary**	**RailCorp**	
EP-08-06-41-00	*Steel Catenary, 193 Contact*		
EP-08-06-42-00	*Steel Catenary, 137 Contact*		
EP-08-07-00-00	**Fixed-Anchored - Twin Contact**	**RailCorp**	
EP-08-07-11-00	*270 Catenary, 2x137 Contact*		
EP-08-08-00-00	**Fixed-Anchored - Contact Only OHW**	**RailCorp**	
EP-08-08-11-00	*193 Contact*		
EP-08-08-12-00	*137 Contact*		
EP-08-09-00-00	**Fixed-Anchored - Compound System OHW**	**BICC**	
EP-08-09-11-00	*327 Catenary, 179 Auxiliary Catenary, 193 Contact*		
EP-08-10-00-00	**Fixed-Anchored - Auxiliary Feeder Wire**	**RailCorp**	
EP-08-10-11-00	*510 Auxiliary Feeder Wire*		
EP-08-10-12-00	*327 Auxiliary Feeder Wire*		
EP-08-10-13-00	*270 Auxiliary Feeder Wire*		
EP-08-10-14-00	*165 Auxiliary Feeder Wire*		

Table 10 - Fixed-Anchored OHW Conductor Configurations

The approximate kilometres of Sydney's OHW in 2012 are tabulated in *Table 11*, sorted into Districts. However, a 2015 document mentions the total at 2,200km, but I cannot gain any updated information to confirm this. In any case, by 2020 this amount would likely have grown substantially.

District	Approx. Total Length * (km)	Comment
North	449	
Central	364	Incl. Freight Lines
West	500	
Illawarra	430	
Total	**1,743**	Incl. Freight Lines

* Main line km's as at beginning of 2012 – Obtained from RailCorp Asset Explorer. (Excludes wiring for crossovers, etc.)

Table 11 - Approx. OHW Conductor Lengths by District c. 2012

3.1.0.5 Design Notes

Design Criteria

Before a new OHW project can be designed, there are a number of fundamental aspects that need to be established for the project. These include nominating the catenary and contact wire numbers (e.g. single or twin contacts) and their respective sizes, tensions and standard heights at support locations, maximum wind speed conditions, etc. The wire sizes are normally dictated by a load flow study based on train simulation of the area, as described in the below sections.

If changes are made to some of these parameters after work has commenced, it will likely require a redesign, which can involve much additional work. This not only affects costs, but it can also be demoralising to design staff and delay progress of the project.

So, it's important to get all parameters firmly established and agreement reached by the start of design for that project.

Wire Sizes

The old *Conductor Design Data Sheets* – T1 (drawing EL0286275) and T1A (EL0286276) – list most of the old OHW conductors used throughout Sydney's OHW and HV Aerial Line (Transmission Line) systems. The 'T' prefix probably indicated 'T'ransmission Lines, with the OHW conductors selected from these. They also show contact wire details (albeit old information).

A lot of the wires are superseded, and I don't think there's been any effort in keeping these conductor sheets up to date. However, the drawings can be helpful to understand a bit of the history and the characteristics of the various conductors, including stranding composition, resistance, breaking load and wind loading.

Hard Drawn Copper

To improve its strength, copper can be *hard-drawn* by forcing it through special dies. The process of drawing the copper through a die reduces its diameter and also *work hardens* it. Do this enough times and it can be made extremely hard throughout its circular cross-section.

The hard drawing process results in a high tensile strength in each solid strand of a wire. This is especially important for use in OHW conductors, which can take on huge mechanical

tensions (often up to the 3:1 safety factor limit). For example, the 270mm² catenary is put under 3 tonnes of tension in the standard regulated OHW system (System 2).

ENERGY TO TRAIN

OHW conductors carry heavy electric current from substations to supply each train, at a voltage of about 1,500V dc. The amount of power supplied to a train is the product of the voltage at the train and the current drawn by the train, at that instant. For example, if the voltage at the train is 1,450V and the instantaneous current is 2,000A, the power supplied at that moment is 2.9 MWatts.

The amount of *energy supplied to the train* is a function of the duration this power is drawn.

The *voltage at the train* is a function of:

- Supply voltage at the closest substation/s (nominally 1,500V). This voltage can drop marginally as load current increases.
- Voltage drop in the OHW conductors from substation/s to the train. This is dependent on the OHW resistance/s from adjacent substation/s and the instantaneous current flowing through the OHW.

  $\longrightarrow V_{drop\text{-}OHW} = I \times R_{OHW}$
- Voltage drop in the track return paths from substation/s to the train. This is dependent on the current flowing through the various track return paths and the overall track resistance. (It may flow through many rails in parallel, with special "Tie-in Bonds" helping to electrically parallel any adjacent tracks to lower this resistance.)

  $\longrightarrow V_{drop\text{-}Track} = I \times R_{Track}$

Refer to *Figure 44*, which is intended to demonstrate the various current paths to and from a train, fed by a substation located to the left side of the drawing. For simplicity and to help aid understanding, the diagram assumes only 1 substation supplying the train, whereas normally there would be another substation (to the right side, albeit probably further away), and therefore the various current paths would be different. But if that other substation is located much further away, then the above flows would still mostly apply.

The voltage at the train can thus diminish with distance from closest substation/s, and it can also diminish as more current is being drawn by the train.

Electrical modelling of this situation is complex. It requires the use of sophisticated computer programs to get a reasonable idea of the electrical power needs for the trains, and to ultimately ensure that the various types of electrical equipment are appropriately rated for the job – including the OHW conductors. It also ensures that the voltage received at the train doesn't go below its lower limit, otherwise on-board low-volt relays can trip train supply.

Inputs to the modelling computer program include:

- Train timetabling,
- Train electrical/motor characteristics (including power for lighting, air conditioning, etc),
- Train mass (including passengers),
- Track characteristics (including track grades, horizontal curves),
- Ambient temperatures,
- Wind conditions,
- Solar radiation,
- etc.

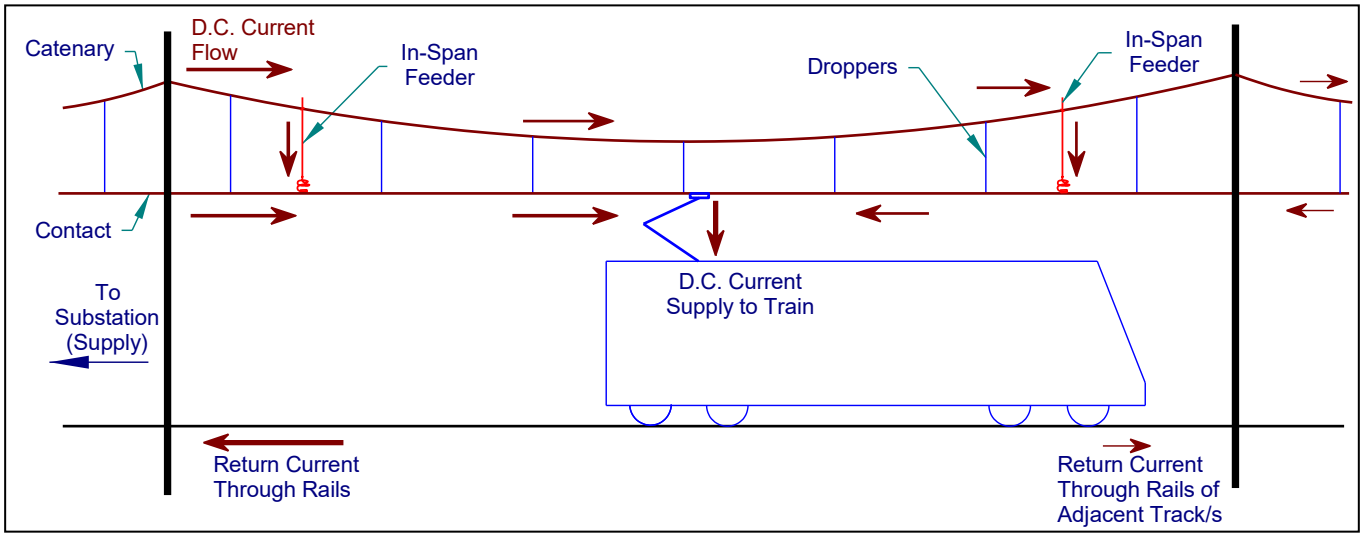


Figure 44 - Current path to Train

The electrical network is modelled as "power studies" (or "load flow studies") which, in the past, were carried out by the Power Systems group within the rail organisation. They had access to a variety of software applications including a comprehensive "train simulation" program. This program modelled electric trains traversing certain parts of the electrified system under interest, and it looked at the electrical demands placed on the various electrical elements: the OHW, HV aerial feeders (transmission lines) and substations / sectioning huts. Different numbers and types of trains could be programmed to travel at once according to user defined timetables, and I think with an amount of "diversification" was applied to better represent a more realistic situation (e.g. delays to timetable).

Among other things, this simulation can determine OHW requirements in terms of minimum amount of copper cross-sectional area needed above the track ("in the air"). This is important information that needs to be passed onto the OHW designers for subsequent design and ultimately construction.

The amount of copper in the OHW is mostly based on the 3 requirements of:

- Not overheating the OHW conductors (preventing the onset of copper annealing), and
- Keeping any fixed-anchored OHW conductors within certain height constraints above trains, and
- Attaining low enough electrical circuit resistances for the electrical protection to reliably operate in case of a fault on the system (i.e. dc circuit breaker settings).

The amount of copper in the air can be increased by:

- Installing thicker catenary and/or contact wires (there's more on why this isn't a good idea later),
- Increasing the number of conductors in parallel (e.g. upgrading from single contact to twin contact), and/or
- Adding 1 or more aerial auxiliary feeders beside the main OHW (which provides a parallel feed path).

The size and configuration of the OHW conductors should be ratified before any significant OHW design work can take place on a new project (to avoid wasted effort and $).

CURRENT PATH TO TRAIN.

At any location on the OHW which is at a reasonable distance from a substation, the current to a train's pantograph located further ahead tends to divide between the catenary and contact wires in proportion to their relative resistances – the larger conductor with less resistance takes a greater share of the current (and in the past this has usually been the catenary wire). In this situation, very little current passes through the in-span feeders (refer to *Figure 44*).

However, in the immediate vicinity of the train, the currents redistribute as the in-span feeders begin offering alternate paths to the pantograph, as shown in this figure.

CURRENT CARRYING CAPACITY

One of the prime requirements of an OHW system is that it must be capable of reliably supplying the necessary amount of power to train traffic, i.e. with no interruptions. To this end, the current carrying capacity of such a system needs to be matched to the mix of trains with their defined power requirements and timetabling in that area.

The current carrying capacity of an OHW system is mostly dictated by the maximum permissible conductor temperature, which needs to be kept below the annealing (softening) temperature of hard-drawn copper – initiation starts at about 80°C to 90°C.

The following aspects influence the OHW rating:

- The number of catenaries and contacts in the OHW system (including the contact-only option).
- The cross-sectional area (sizes) of catenary and contact wires in parallel.
- The material used for catenary and contact (e.g. because of its relatively high electrical resistance, steel catenary should be configured to carry no current, only support the contact wire).
- The mode of tensioning the OHW, i.e. whether it is fixed-anchored or regulated tension OHW. Fixed-anchored OHW at hot temperatures results in a lot more catenary sag at mid-bay, which then causes the supported contact wire to lower – but there is a limit to how low this contact height can be in a bay.
- The minimum remaining *stiffness* in the contact wire to provide suitable pantograph interaction at speed. This is a problem with fixed-anchored contact wire where its tension can plummet to extremely low values when hot (see below).
- The ambient weather conditions, including solar radiation, maximum ambient temperatures and accompanying wind speeds – affecting the maximum wire temperature.

Contact Wire Stiffness

In regard to the second last dot point above, the term "stiffness" of the contact wire relates to its ability to control the pantograph uplift as it passes through. The stiffness of the contact wire is a function of the tension in the wire, as well as its weight per metre (and this wire wears over time).

The contact wire needs to be relatively stiff at all times, otherwise it can become a dynamic problem for the pantograph / contact wire interface, especially with several uplifting pantographs located fairly close together on trains travelling at reasonable speeds. If insufficient stiffness causes the contact wire to move wildly about, there may be significant arcing as a consequence (particularly for trailing pantographs on the train).

For regulated OHW, the contact tension remains relatively high. However, for fixed-anchored systems, the tension plummets when hot, e.g. for 193mm² contact wire, tension = 13.35kN @ 21°C → only 2kN @ 55°C (which is a mere 15% of the design tension).

At low tension, the contact wire tends to take on its original coiled shape (when it was initially wound on a wire drum prior to installation). This "memory" effect happens even after 30 years or so of working life. This revealed coil shape can have a detrimental effect on the pantograph interface as the train travels.

This is one of the reasons why the *Copper Efficiency* figures in the last column in *Table 8* are low in fixed-anchored OHW systems compared to the equivalent regulated OHW system. E.g. for a 270mm² catenary / 193mm² contact system, the *copper efficiency* if it's regulated is 3.84, but if the same wire is installed as fixed-anchored, the value is only 1.89 – less than half!

In other words, the copper cannot pass anywhere near as much current when a fixed-anchored contact wire is hot and its tension is low, and this is what mostly limits its overall current rating (and speed rating too).

Refer to *Section 3.1.2.5*, *Contact Wire Stiffness* for more details.

AUXILIARY FEEDERS

To improve any deficiency in OHW current rating, additional copper may need to be installed, e.g. adding an *auxiliary feeder* (A/F). It becomes effectively another independent fixed-anchored catenary wire installed in parallel with the main OHW.

The auxiliary feeder is connected to the main catenary wire at regular intervals using a*uxiliary feeder jumpers* (stranded copper wire of the same CSA as the catenary wire).

Unfortunately, adding an auxiliary feeder adds to the complexity of the OHW and ultimately the initial construction and ongoing maintenance costs into the future.

The current tendency is to avoid the use of auxiliary feeders, which run somewhat parallel to the main OHW conductors, but can often depart in direction and be located well off to the side of this OHW by necessity (due to obstacles in the path).

The reason for shying away from auxiliary feeders seems to be because of the potential hazard they pose. As they are sometimes quite remote from the main OHW conductors, it is not always clear that they belong to these conductors. In addition, there are fault protection considerations – if the A/F wire snaps, it needs to fall onto the track or something else that's rail-connected, in order to trip supply and render the situation safer (otherwise it could remain alive).

Instead of installing auxiliary feeders, the added copper cross-sectional area is better achieved by increasing the size, or (preferably) the number, of OHW conductors that are directly supplying the trains, e.g. having a twin catenary / twin contact system.

THERMAL ASPECTS OF OHW

Wire Expansion & Contraction with Temperature

Typical copper expansion and contraction with temperature changes from the design value are shown in *Table 12* (assuming a 25°C design temperature).

The important thing to note about this above table is that:

> *for every **100m** of wire length,*
> *its length changes by **17mm** for every **10C°** change in temperature.*

Different alloys of copper may lead to slightly different rates of expansion, but the above is indicative of the thermal expansion character of copper conductors. And it's something that needs to be taken into account when designing with conductor systems, whether they be regulated or fixed-anchored (but for different reasons – see *Figure 24*).

Copper Conductor - Length Change With Temperature

Alpha (/°C): **1.7E-05**
Design Temp (°C): **25**

	Change in Copper Conductor Length (in metres) Due to Changes in Temperature.														
Distance (m)	**-5°C**	**0°C**	**5°C**	**10°C**	**15°C**	**20°C**	**25°C**	**30°C**	**35°C**	**40°C**	**45°C**	**50°C**	**55°C**	**60°C**	**65°C**
0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
50	-0.026	-0.021	-0.017	-0.013	-0.009	-0.004	0.000	0.004	0.009	0.013	0.017	0.021	0.026	0.030	0.034
100	-0.051	-0.043	-0.034	-0.026	-0.017	-0.009	0.000	0.009	0.017	0.026	0.034	0.043	0.051	0.060	0.068
150	-0.077	-0.064	-0.051	-0.038	-0.026	-0.013	0.000	0.013	0.026	0.038	0.051	0.064	0.077	0.089	0.102
200	-0.102	-0.085	-0.068	-0.051	-0.034	-0.017	0.000	0.017	0.034	0.051	0.068	0.085	0.102	0.119	0.136
250	-0.128	-0.106	-0.085	-0.064	-0.043	-0.021	0.000	0.021	0.043	0.064	0.085	0.106	0.128	0.149	0.170
300	-0.153	-0.128	-0.102	-0.077	-0.051	-0.026	0.000	0.026	0.051	0.077	0.102	0.128	0.153	0.179	0.204
350	-0.179	-0.149	-0.119	-0.089	-0.060	-0.030	0.000	0.030	0.060	0.089	0.119	0.149	0.179	0.208	0.238
400	-0.204	-0.170	-0.136	-0.102	-0.068	-0.034	0.000	0.034	0.068	0.102	0.136	0.170	0.204	0.238	0.272
450	-0.230	-0.191	-0.153	-0.115	-0.077	-0.038	0.000	0.038	0.077	0.115	0.153	0.191	0.230	0.268	0.306
500	-0.255	-0.213	-0.170	-0.128	-0.085	-0.043	0.000	0.043	0.085	0.128	0.170	0.213	0.255	0.298	0.340
550	-0.281	-0.234	-0.187	-0.140	-0.094	-0.047	0.000	0.047	0.094	0.140	0.187	0.234	0.281	0.327	0.374
600	-0.306	-0.255	-0.204	-0.153	-0.102	-0.051	0.000	0.051	0.102	0.153	0.204	0.255	0.306	0.357	0.408
650	-0.332	-0.276	-0.221	-0.166	-0.111	-0.055	0.000	0.055	0.111	0.166	0.221	0.276	0.332	0.387	0.442
700	-0.357	-0.298	-0.238	-0.179	-0.119	-0.060	0.000	0.060	0.119	0.179	0.238	0.298	0.357	0.417	0.476
750	-0.383	-0.319	-0.255	-0.191	-0.128	-0.064	0.000	0.064	0.128	0.191	0.255	0.319	0.383	0.446	0.510
800	-0.408	-0.340	-0.272	-0.204	-0.136	-0.068	0.000	0.068	0.136	0.204	0.272	0.340	0.408	0.476	0.544
850	-0.434	-0.361	-0.289	-0.217	-0.145	-0.072	0.000	0.072	0.145	0.217	0.289	0.361	0.434	0.506	0.578
900	-0.459	-0.383	-0.306	-0.230	-0.153	-0.077	0.000	0.077	0.153	0.230	0.306	0.383	0.459	0.536	0.612
950	-0.485	-0.404	-0.323	-0.242	-0.162	-0.081	0.000	0.081	0.162	0.242	0.323	0.404	0.485	0.565	0.646
1,000	-0.510	-0.425	-0.340	-0.255	-0.170	-0.085	0.000	0.085	0.170	0.255	0.340	0.425	0.510	0.595	0.680
1,050	-0.536	-0.446	-0.357	-0.268	-0.179	-0.089	0.000	0.089	0.179	0.268	0.357	0.446	0.536	0.625	0.714
1,100	-0.561	-0.468	-0.374	-0.281	-0.187	-0.094	0.000	0.094	0.187	0.281	0.374	0.468	0.561	0.655	0.748
1,150	-0.587	-0.489	-0.391	-0.293	-0.196	-0.098	0.000	0.098	0.196	0.293	0.391	0.489	0.587	0.684	0.782
1,200	-0.612	-0.510	-0.408	-0.306	-0.204	-0.102	0.000	0.102	0.204	0.306	0.408	0.510	0.612	0.714	0.816

Table 12 - Copper Wire length change with Temperature

Thermal Time Constant

Heavy electric current flowing in the OHW conductors causes them to heat up because of the conductor's electrical resistance.

The OHW conductors have a *thermal time constant* of about 20 minutes. This means that, when the current stops, it takes about 20 minutes for the higher temperature of the heated conductor to naturally come back to almost ambient temperature.

For smaller conductors, the thermal time constant can be much less than 20 minutes, and this can be a real advantage to the OHW.

Conversely, large conductors have a higher thermal time constant. This is because large conductors are less effective at cooling, due to the larger ratio of cross-sectional area (which tends to store heat) to surface area (which helps it to cool).

The amount of heavy current (I) being passed, in conjunction with its duration (t), both cause the OHW to heat up to a higher temperature, viz. Energy ~ I^2 t.

The main problem with this relatively large thermal time constant of about 20 minutes is that, if the wire hasn't had time to cool down before another train comes along, the added heavy current drawn by the next train will likely increase the OHW temperature to a higher level than before, because the new temperature rise starts from a higher initial value. And another train soon after can do likewise. This step-wise cumulative temperature effect can compound the temperature rise problem – until the wire becomes so hot that it finally begins to *anneal*!

As described initially in *Section 2.5.7*, if the temperature of the OHW conductors approaches the initial "annealing" temperature (about 80°C for hard-drawn copper), then these conductors could begin to soften (anneal), which will reduce its tensile strength, and the conductor could start to permanently stretch. If this happens, it may adversely affect the performance of the

OHW. For example, a fixed-anchored contact wire could then sag and touch the roof of a train, thus interrupting supply. Or the wire simply stretches so much that its reduced cross-sectional area is insufficient for the significant tension and so becomes overstressed – it snaps and falls to the ground. If this stretching happens in a regulated system, the weights might permanently lower, which is sometimes a tell-tale sign of problems (to be investigated).

The very real risk of annealing is one that should be properly controlled. In addition, any stretch caused by annealing is permanent, and will likely require portions of the run (if not the entire run) of conductors to be replaced, and the distances can be in kilometres!

The risk of overheating is greatest when the ambient temperature is already hot, because it then doesn't take much current/duration to heat the wire up towards annealing temperature.

The temperature *difference* between the conductor and its surrounding cooler ambient temperature helps drive the conductor to cool down. In addition, cross winds and radiation from this hot conductor also aid in the cooling process – see below.

Obviously great care needs to be exercised to ensure that the OHW conductors do not get anywhere near the annealing temperature. This is one of the crucial aspects that is analysed and addressed by various load flow studies that are carried out on the electrified network from time to time, as conditions change.

Heating & Cooling Mechanisms

Heat is thermal energy – it can be transferred from one place to another by *convection* and *conduction* (which involve particles) and by *radiation* (which involves electromagnetic waves). Refer to *Figure 45* for these mechanisms.

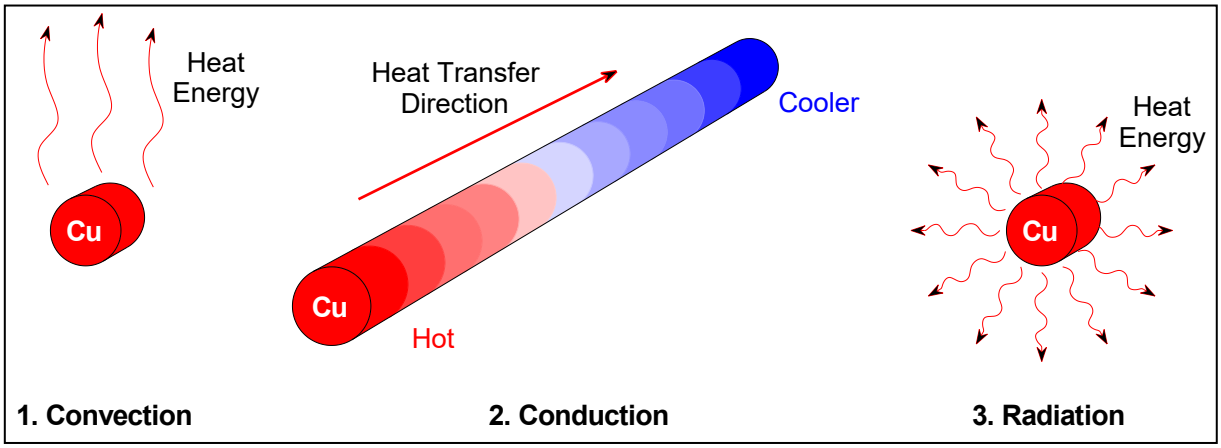


Figure 45 - Wire cooling mechanisms

Getting Hot …

The copper catenary and contact wires generally heat up by the following means:

- When passing *heavy current* (proportional to $I^2.R$) for a certain duration of *time*.
- With *higher surrounding ambient temperature* (a hot day).
- By *solar radiation* acting onto the wire.

Cooling Down …

The conductors generally cool down by means of:

- *Convection* currents – the transfer of heat from warmer areas to cooler spaces. Hot air rises and takes the heat with it. Wind flowing over the conductor can force convection currents to transfer some of the heat downwind. *Aspect 1* in *Figure 45*.

- *Conduction* – the cooling that occurs along the conductor when near a cooler thermal mass. This mass can be a suspension clamp for instance. Rain, snow or ice in contact with the outside of the conductors are ways that forced conduction can accelerate the cooling effect on the conductor itself. *Aspect 2* in *Figure 45*
- *Radiation* – the transfer of heat via electromagnetic waves into the atmosphere. *Aspect 3* in *Figure 45*.

Ways to Reduce OHW Temperature Rise

As mentioned previously, to combat the temperature rise problem, one solution is to increase the amount of copper cross-sectional area in the OHW, which reduces its electrical resistance. This can be done by replacing with bigger conductor/s, but this increases the thermal time constant which is not so good.

Alternatively, adding an auxiliary feeder next to the main catenary can help reduce temperatures, by helping carry the current and having a cooling profile consistent with the main catenary wire. This can provide a better solution than using larger conductors.

Example 1:

When we designed the OHW for the Airport Line, load flow studies highlighted that the OHW for Wolli Creek Station required **2** additional auxiliary feeders in parallel with the twin contact fixed-anchored OHW system – that's 5 conductors in parallel, giving a huge 1,084mm² copper cross-sectional area. This rather drastic action was needed because:

- The (then new) Wolli Creek Station was located below ground level but was open and subjected to solar radiation.
- There was no opportunity for cooling cross winds to help – in summer it would be like an oven.
- There was a steep upward gradient on the departure side in the down direction, requiring huge start-up and acceleration currents from the trains for about 500m or so to the outside surface.
- the substation feeding points to the OHW were also located near the base of this stretch.

All in all, quite a bad situation for feeding the running trains. (Refer to *Section 4.1.5*).

A third option, which is the current trend, is to use a greater number of smaller conductors in the OHW system, and with the individual catenary and contact wire cross-sectional areas roughly matched. This helps keep the thermal time constant smaller by providing more efficient conductor cooling (quicker to cool down).

Example 2:

A good example is the recently introduced twin 165mm² catenary / twin 137mm² contact regulated OHW system (*OHW System 15*). It is rated at 2,800 amps as shown in *Table 8*. To my thinking, this is the best high current OHW system, and it's the one that was installed across the Sydney Harbour Bridge during the recent OHW upgrade program. The mechanical loadings onto the various support structures are only about the same as the standard OHW system (*System 2* – rated at 2,050A) but it results in about 37% more current carrying capacity.

Contrast this system with the highest current carrying capacity OHW system – *System 12* (2x270mm² catenaries supporting 2x137mm² contacts). Its capacity is a huge 3,180A continuous. However, the additional 13% current capacity (over *System 15* above) comes at the expense of the additional weight and other loads from this conductor system onto the various OHW support structures and anchors, which are huge (32% more catenary tension, 28% more catenary wind load and 32% more system weight).

Increased Loading in OHW

Currently the need for more efficient OHW in Sydney comes from:

- A *greater number of trains* running these days (timetabled more frequently). The desire from train operations seems to be to run trains with only 3-minute headways! This can readily result in that cumulative temperature rise effect on the OHW conductors described above.
- Trains with *greater acceleration* (e.g. Waratah trains). This draws heavier currents and for longer periods as the train comes up to speed.
- Trains with *greater initial mass* (apparently to meet crash worthiness requirements).
- Trains are having *greater passenger "crush load" capacities*. According to official RailCorp documents, the recently acquired 8-car "Waratah" double deck trains have the capacity to transport 2,150 people, plus 16 in wheelchairs. This is a huge amount of overall weight to transfer around the rail system.
- *Air conditioning on all trains* (very few had A/C until the past few decades).

Each of the above aspects have added to the energy demand from the electrical system, which is now far greater than it ever used to be.

Since the voltage to the train is relatively fixed at around 1,500V, the increased energy demand translates to increased current in the OHW.

It's actually a little worse than this, because heavier currents passing in the OHW conductors leads to additional *voltage drop* through resistance in the OHW, track and other components, leading to a reduced voltage at the train itself. (This is actually made a little worse by the fact that the electrical resistance itself also increases with temperature.) But the reduced voltage at the train then requires even more current from the OHW to deliver the same amount of power demanded on-board, thus compounding the problem.

The OHW conductors need to supply this higher electric current demand, but the situation is further worsened because trains now have *regenerative braking*, which acts to slow trains down by turning each train into a generator and pumping current back into the system (while braking) for nearby trains to benefit from – if they can. Unfortunately, this form of braking further heats up the OHW $\sim I^2 R_{OHW}$. This is one of the reasons for the urgent "Traction System Upgrade" (TSU) project that has progressed throughout the network over the past decade or two – to identify and electrically strengthen the weak areas of the electrical network.

A previous load flow expert mentioned that it is now the *current return path through the rails* that the trains run on, that is potentially becoming a limit to supplying more power to trains in the 1500V system. Steel has a much higher electrical resistivity, and these steel rails can also heat up $\sim I^2 R_{Track}$. The resulting temperature rise in the rails has to be limited, especially on hot days, otherwise the track condition may suffer, e.g. tendency to move or buckle(?). Limiting the temperature can be achieved by limiting the return current – somehow.

The point being made is that load flow studies have *apparently* shown that Sydney is reaching a stage where sometimes it cannot always just simply add another auxiliary feeder in parallel with the OHW conductors to increase the current to the train, because the return path (rails) are starting to become another limit to supplying more power. I understand that reduced substation spacing may also help in this regard.

The most desirable way of getting more power to a train is to increase the supply voltage. Indeed, some overseas railways operate at double our dc voltage i.e. 3,000Vdc. (Doubling the voltage doubles the available power to the trains for the same level of current.) But ultimately, the big benefits occur at 25kv ac (for a few reasons).

Some Benefits of 25kV ac

The 1500V dc system has a relatively limited capacity to power trains. This is due mainly to the finite amount of *current* that can be reliably supplied through the OHW, and also now through the track rails (negative return).

But so far, Sydney's OHW system has coped well, probably because of the periodic load flow modelling that has been and continues to be performed, based on any changes to (new) train characteristics and traffic density. This modelling aims to identify any areas of electrical weakness throughout the electrified network, so that corrective action can take place to ward off any "reliability of supply" issues.

Of course, the far superior solution is to supply trains at 25kV and employing alternating current (ac), which also avoids one of the main drawbacks with dc – electrolysis corrosion.

Heavy current is the enemy of OHW, and the 25kV system needs only about 6% of the current that the 1500V system needs to supply trains, e.g. a train demanding 3,000 amps from the 1500V OHW would instead demand only about 200 amps from the 25kV OHW. Also, there's likely much more ongoing wasted energy (caused by passing large magnitude current, viz. $I^2 R$) that has to be accepted as a consequence of running this 1500V system.

The 25kV system only needs small conductor sizes, since the current being passed is small. The rest of the infrastructure can likewise be much lighter gauge because of the much reduced mechanical loads and tensions involved, e.g. the OHW support structures can be more slender. And the conductors don't heat up much with the small currents, which means the temperature rise is smaller, and there's very little increased resistance and power loss in the conductors as a consequence.

Another big benefit of 25kV is the much greater spacing between substations, resulting in far fewer substations needed to supply power (and they're simpler since there is no need for rectification to dc).

This higher voltage can also allow far greater train speeds if required – the available power to each train is immense.

The significant down side is that 25kV requires greater electrical clearances (typically almost twice the distance – 150mm becomes something closer to 300mm), which is a problem when you consider the existing minimal OHW clearances under civil infrastructure such as overline bridges and, more importantly, inside tunnels (and especially the older tunnels). There are other issues as well that need to be considered.

Sydney is likely too far committed to 1,500V in the suburban network to ever consider the massive expense of any upgrade to 25kV, unless localised in some way. And there are no electric freight trains that could otherwise greatly benefit from such a conversion (although it could be a good argument for their reintroduction).

As mentioned above, the existing 1,500V dc system is still able to meet Sydney's current needs, since it only operates trains at moderate speeds (up to 130km/h or so) and with reasonable headways.

VIRTUAL SPAN

It is most important to understand the fundamentals of *virtual span* (VS) as it applies to any fixed-anchored OHW conductors. The VS value is used to calculate the tension in a conductor as a function of its temperature, by solving a complex cubic equation. (A wire lengthens when it gets hotter, thus reducing its tension.)

The calculation of virtual span involves performing a mathematical calculation which results in a distance value. This value is a bit like a "representative" bay length, taken between multiple consecutive conductor support points. For OHW work, virtual span for the fixed-

anchored *contact wire* is normally about 4.57m. For the *catenary wire* it's usually much larger – between 20m and 73m and requires calculating in each instance.

The main idea with virtual span is that …

> *The **smaller** the **virtual span***
> *the **greater** the **tension change** in response*
> *to **temperature change.***

It's always beneficial to limit the *amount* of change in conductor tension as its temperature changes between the extremes of hot and cold. Extremely low tensions can affect how much the conductor sags at mid-bay and blows out with wind, while high tensions can affect the strength of materials needed to hold the wire, as well as the wire strength itself.

OHW conductors with small virtual span values can experience huge tension changes with temperature (both hot and cold), and this situation needs to be checked out in the design process and dealt with carefully, otherwise several nasty outcomes can occur. For this reason, it is always undesirable to have a small virtual span.

Conversely, if the virtual span is large, the tension change resulting from temperature change will be less, making it easier to control the behaviour of the OHW and how it interacts with trains.

The fixed-anchored *contact wire* normally has the same virtual span throughout the entire run, because its value is based on the somewhat regular distance between the droppers supporting it (as mentioned above, for fixed-anchored OHW it's typically about 4.57m).

On the other hand, the catenary wire usually has a much larger virtual span (typically between 20m and 73m), however there may be several different values of virtual span throughout the wire run (depending on where the catenary wire is locked from longitudinal movement).

So, designers try to maximise the fixed-anchored catenary virtual span. There's usually not a lot that can be done about the contact wire's necessarily small virtual span, and the consequent huge tension changes with temperature should be handled with great care (especially the amount of blowout under windy conditions, sometimes requiring additional pull-off locations to help control this).

See *Section 3.1.1.5, Tension Changes* further on for much more detail as it relates to the catenary wire.

For a more thorough understanding of virtual span, refer to the Sydney Trains document GL E 73002, "Understanding Virtual Span", first published in 2015.

DESIGN TEMPERATURE

The *design temperature* is an important reference in OHW work – it establishes a standard temperature about which the behaviour of the OHW conductors at other temperatures can be predicted and catered for. This is especially important at the design stage for new or upgraded OHW.

The original design temperature for Sydney's OHW was 21°C. As I understand it, the 21°C figure came from 70°F converted, and this temperature was used to represent "standard temperature" for most scientific calculations in the good old days (and it's what we were taught to use at school).

So up until recently the design temperature was 21°C. But 25°C is probably a much better design temperature for the future, as argued below.

ADOPTING A HIGHER DESIGN TEMPERATURE

There have been recent moves to increase this design temperature to 25°C, and the first project to use this new temperature was the Airport Line, which was commissioned for the 2000 Olympics. Hopefully one day this higher temperature will be incorporated into the Standards (if it hasn't been already).

The argument for a higher design temperature in the Airport Line was based on the understanding that the minimum tunnel temperature was 10°C, so it made sense to bump the design temperature up a bit, to take advantage of the warmer "cold" conditions, and therefore giving ***less*** of a temperature difference from design temperature to "hot" conditions (which is beneficial – see below).

The maximum temperatures are governed by ambient conditions and by the power demand from trains, as modelled by load flow simulations. The hottest catenary and contact wire temperatures are usually reached just outside a substation where a heavier current is drawn and for a longer time. (When a train is immediately outside a substation, virtually all current for the train comes from it. As the train heads towards the next substation, the train current is proportioned between the 2 nearest substations.)

Benefits of adopting a higher design temperature of 25°C differ for the 2 tensioning modes (with no apparent disadvantages), as described below.

For Fixed-Anchored OHW

In a fixed-anchored system, the actual temperature deviation from the design value can have different adverse outcomes when the OHW is hot versus when it's cold – refer back to *Figure 24*. For most situations in Sydney, the hot temperature used is 55°C and the cold temperature is -5°C. Thus …

- For a design temperature of 21°C, the deviation is 34°C (hot) and 26°C (cold).
- For a design temperature of 25°C, the deviation is 30°C (hot) and 30°C (cold) – the deviations are equal.

So, 25°C is exactly midway, whereas there's a 4C° greater change of 34°C (in the hot direction) when 21°C is used. This might seem trivial, but unfortunately, it's the hot temperature deviation that causes most of the likely problems in a fixed-anchored OHW system (not the cold temperature). A working understanding of this is borne out when designing the OHW.

Adverse outcomes …

Hot ...

The slack tension resulting from hot wire can cause increased conductor sag and more blowout, and it can ultimately result in poor pantograph dynamic performance with trains operating at high speed. In the extreme case, the catenary wire can allow the contact wire to sag so much at mid-bay as to touch the train's roof and trip the circuit breakers (stop trains).

The big benefit of adopting a higher design temperature of 25°C for a fixed-anchored OHW system is that the "slack tensions", resulting from hot wire, deviate less from design tension. This means the contact wire height at mid-bay lowers in hot weather *by a lesser amount*. This in turn leads to better overall pantograph performance (especially at speed), better mid-bay height clearances, and less blowout with wind. Ultimately, this means better control of the wire and less chance of service disruptions.

Cold ...

The high tension of cold wire can cause the conductors to become highly stressed, but that's why we use a 3:1 safety factor at that temperature. The higher tensile and resulting radial loads can also stress the various support structures, but they too should be designed for this. It can also reduce the catenary sag, which may reduce vertical clearances to bridges, etc. – again, the design should take this into account.

For Regulated Tension OHW

The upper and lower temperature limits for regulated OHW seem to be 60°C and -5°C respectively, as shown on the various tension regulator drawings, and is likely an average temperature taken over the entire wire run.

With these temperature extremes in mind, the benefits of a higher design temperature of 25°C are listed below.

- ***A Better Median Temperature.***
  It better represents a "median" temperature, with the cold and hot temperature excursions from the design value being a closer match. E.g. In the open air,
  Cold: -5°C to 25°C = 30C° change in temperature, and
  Hot: 25°C to 60°C = 35C° change in temperature.
  This is a closer match (different by 5C°) compared with the design temperature of 21°C which yields 26C° and 39C° respectively (which is different by 13C°).
  The midway point in this temperature range is 27.5°C (giving ±32.5°C). Adopting 25°C as the standard temperature is very close to the ideal 27.5°C.
  While this middle temperature has no direct effect on the movement or setup of the weights, it does have a direct bearing on other issues as detailed below.
  It would also help when setting up Feeder or Potential Jumpers, for a closer to equal wire excursion with hot and cold temperatures about this better "median" design temperature.
- ***Improved Stagger Control with Cantilever Swing.***
  Another aspect that can benefit from the higher design temperature is the change in contact stagger with temperature. This results from the wire moving longitudinally, causing the pivoting cantilever frames (including pull-off arms) to move in an arc in sympathy (when viewed from above). Refer to *Section 3.2.0.5*, *Stagger Change with Regulated Contact Wire* for more details, and especially *Figure 200*.
  Because the contact wire expands and contracts with temperature, its movement can vary the contact stagger from its installed design value, due to the "swing" of the pull-off arrangement about its pivot point.
  The expansion and contraction with temperature is linear (and is independent of the copper conductor cross-sectional area).
  At the OHW support & registration location, the shorter the pull-off distance from its pivot point to the contact wire, the greater the change in contact stagger. And eventually this stagger change can be so large as to adversely affect "Pantograph Security", either at the support location or somewhere near mid bay (especially under high wind conditions).
  Using short arms (typically 1,200mm length) directly into a post type insulator on a drop vertical gives the worst stagger changes with temperature.
  In addition, any permanent contact wire stretch (e.g. Gosford to Newcastle OHW) can exacerbate the hot temperature stagger change (until the stretch is noticed and corrected).
  Ideally the cantilever pull-off arrangements should be set to being perpendicular to track (in plan view) at 27.5°C, but using the proposed 25°C design temperature is much better than the old 21°C reference.
  This would give approximately uniform arm swing (and thus more equalised stagger changes) under both cold and hot temperatures, which is desirable.
  Refer to *Section 3.2.0.5* for more details.

If the likely phenomenon of "climate change" turns out to be correct, then there are going to be more days that are hotter than before, so the small 4C° change from 21°C to 25°C seems a prudent thing to do in any case.

One last (minor) benefit is that 25°C is a nice round number (unlike 21°C) and sits nicely in increments of 5C°. Refer to *Table 12* for example.

Clearly there is much to be gained by changing the standard design temperature to 25°C, and I expect that this will eventually be adopted into the Electrification Standard (if not already).

3.1.0.6 Status (c. 2014)

Current policy is to regulate new OHW wherever this is practical (and certainly for the open route). Typically, this would be done with one (or more) of the following standard systems:

- *OHW system 2* (270mm² catenary / 2x137mm² contact).

However, for *heavier currents* the following systems are available:

- *OHW system 12* (2x270mm² catenary / 2x137mm² contact) and
- *OHW system 15* (2x165mm² catenary / 2x137mm² contact) – preferred (if sufficient).

Sidings and crossover runs that don't require much power can use:

- *OHW system 10* (165mm² catenary / 193mm² contact).

OHW catenary system for *tunnels* is typically designed using *fixed-anchored* tensioning:

- *OHW system 28* (270mm² catenary / 2x137mm² contact).

OHW upgrade programs have been generally renewing as regulated OHW (what was once fixed-anchored OHW).

3.1.0.7 Reference

For current OHW standards, refer to Electrical Standards publication:

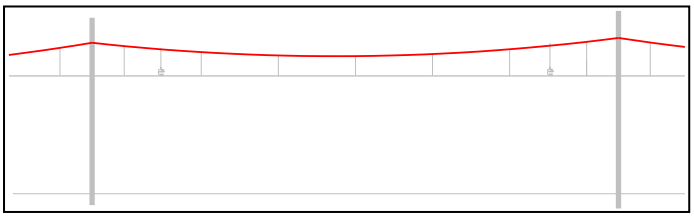
- EP-000801-SP, "Overhead Wiring Standards for Electrification of New Routes".

For details of available OHW systems and selection guides, refer to:

- EP-08000016-SP, "Designations of OHW Conductor Systems", and
- EP-08000017-SP, "OHW Conductor System Selection".

For guidelines on how to deal with temperature extremes in fixed-anchored OHW, refer to Sydney Trains document GL E 73002, "Understanding Virtual Span".

3.1.1 Catenary Wire



3.1.1.1 Description

The catenary wire is a multi-stranded conductor and is located above the contact wire. (The term is often abbreviated and referred to as the "caty".)

This wire is usually made of copper, although some areas with steel catenary may still exist.

A catenary wire is held up by suspension insulators at various *catenary support* locations, which define the end of the previous OHW *bay* and start of the next bay. A catenary wire run – from anchor to anchor – rarely exceeds 2km, and often includes 30 bays or more.

Throughout each bay, various attachments are made to the catenary, mostly to support the contact wire (with droppers) and to feed current to this wire (using in-span feeders).

The catenary wire is under large applied tension, and takes up a parabolic shape in each bay due to sagging (under gravity) from the combined weight of itself and the various other supported conductor components, including contact wire, droppers, in-span feeders, section insulators, etc.

3.1.1.2 Function

The catenary wire supports the contact wire and allows the contact wire to have a flat (or near flat) profile, which is needed for smooth, high speed pantograph running.

This wire is designed for carrying *high current* (in conjunction with the contact wire) and, thanks to it being made of copper, has *low electrical resistance*. Both these aspects are needed for reliably supplying power to each passing train.

The catenary is held up under considerable tension so as to limit the amount of sag between support locations.

An *auxiliary feeder* is another somewhat independent catenary wire that can be added adjacent to the main catenary, to help supply additional power to trains by offering a parallel current path and so reducing the temperature of the main OHW conductors. It can also help to reduce the overall resistance of the OHW, which helps with its electrical protection.

3.1.1.3 Typical Components

(Not applicable).

3.1.1.4 Configuration

The catenary is made of multi-stranded hard-drawn copper wire. The multi-strands allow for a degree of flexibility, which is especially needed during its installation.

A small (almost negligible and diminishing) proportion of the electrified system has steel catenary, which is not intended to carry current and is only there to support the relatively flat fixed-anchored contact wire.

The various catenary sizes are listed in *Table 13* and a comparison of relative sizes is shown in *Figure 46*.

A run of OHW can have a single catenary or twin catenaries located side-by-side, supporting the contact wire/s.

An auxiliary feeder, if installed, usually has the same characteristics as the main catenary it's trying to aid. It's usually the same cross-sectional size and is designed to have the same

parabolic shape (and sag) as the main catenary, which is a requirement that can help highlight possible problems during its service life. In this case, the wire tension will be less because it doesn't need to support any other loads in each bay, i.e. no contact wire, droppers, etc.

Area	Conductor Stranding	Conductor Material	Diameter (mm)	Weight (N/m)	Break Load (kN)
91mm² (0.14 in²)	7/4.06mm	Steel	12.19	7.03	
165mm² (0.25 in²)	19/3.35mm	Hard Drawn Copper	16.64	14.59	65
179mm² (0.28 in²)	19/3.48mm	Hard Drawn Copper	17.40	15.98	70
270mm². (0.4 in²)	37/3.05mm (or 61/2.36mm)	Hard Drawn Copper	21.34*	23.97*	109*
327mm² (0.5 in²)	37/3.35mm	Hard Drawn Copper	23.47	29.08	128
510mm² (0.8 in²)	37/4.19mm	Hard Drawn Copper	29.34	45.31	192

Notes: Conductor stranding has format of (Number of strands / strand diameter)

* – Figures for 37/3.05mm conductor (not 61/2.36mm).

Table 13 - Standard Catenary sizes & details

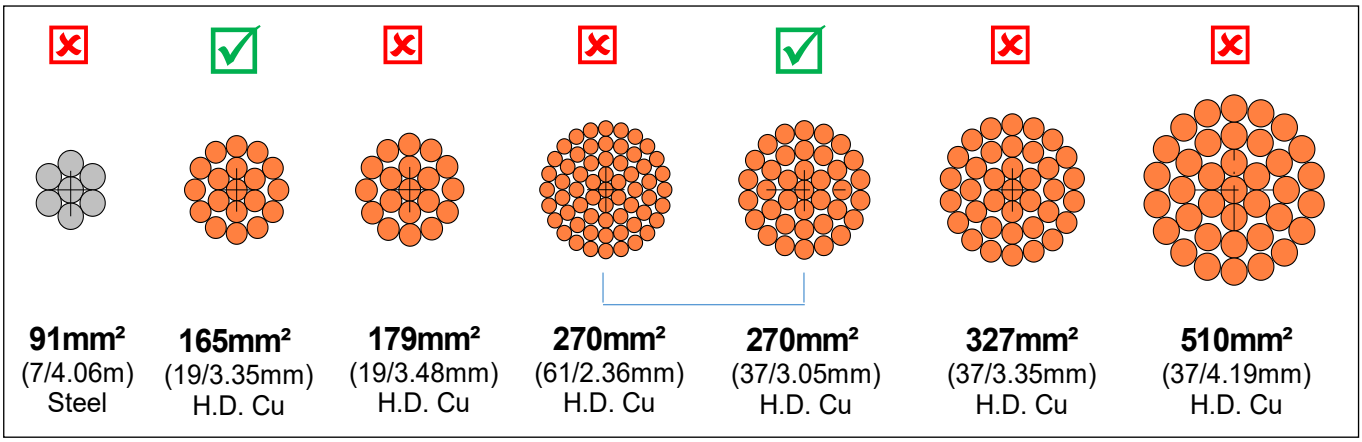


Figure 46 - Cross-sections of various Catenaries – relative sizes & metals (past & current)

An observation:

There are two configurations of the 270mm² catenary wire, as shown in *Figure 46*:

- The initial 61 strands of 2.36mm diameter wire (no longer used), and
- The current 37 strands of 3.05mm diameter wire.

The initial wire was likely the standard size used throughout the network in the early days of electrification. For instance, the recent OHW upgrade on the Sydney Harbour Bridge revealed the old catenary (from the 1930s) to be this 61-stranded configuration, and after about 80 years of service it was still in relatively good condition, albeit externally covered in the obligatory green copper oxide colour, and absolutely packed internally with black dust from traffic, pollution, etc. trapped within the stranding gaps.

So why did they change from the 61 strands to the 37 strand equivalent?

There are suggestions that the fewer number of *larger size strands* were less likely to creep (permanently lengthen) over time, and it also provided a marginal advantage in terms of overall strength. Refer to "Liverpool – Campbelltown – Glenlee Electrification" report by A. Hamilton.

But I suspect this was also done for reasons of *robustness*.

My reasoning …

The smaller diameter strands are more susceptible to breakage when struck by some heavy object. This can happen during construction (e.g. tools striking it), but more importantly it can happen throughout its service life. This damage can more readily happen because most of the OHW is exposed to the elements, notably direct lightning strikes, and also to objects such as nearby trees or power poles, which can and do often fall onto the catenary under windy conditions. (See *Figure 641* much further on for an instance of this.)

With the catenary made from larger diameter strands, each strand can take more punishment before the strand or strands ultimately snap, compared with the smaller diameter strand.

The current policy: if any single catenary strand breaks it needs to be repaired.

Left alone, the broken strand/s would begin to unravel which could eventually become so long as to threaten the nearby infrastructure, including the top of passing trains. This could be dangerous and can also severely effect on-time running.

Also, a cut strand cannot conduct current and so it can't help share the load current burden, which is no good (especially these days with greater and more prolonged load currents being drawn by trains).

Simply wrapping insulation tape or similar over the area to contain the damaged strand may temporarily prevent it from unravelling, but it does not help with the need to pass heavy current. So, this can only be a very temporary remedial action until it is properly repaired as soon as is practical.

Broken strands can be effectively repaired by cutting the conductor near that point of damage and "splicing" the conductor with a "full-splice", or in the old days, a pair of back-to-back "snail clamps" with a bridging catenary would have been used, or a "cone splice", etc. – refer to *Section 3.1.8* for more information on these components. Note that there is no full-splice wrapon fitting available for the old 61 stranded catenary wire.

Any catenary repair is time consuming, and it results in a less than desirable outcome (unsightly / more equipment in the air to maintain / possible added electrical resistance across the splice / greater likelihood of future mechanical failure, etc.).

Therefore, incorporating the larger diameter stranding makes it less likely that a repair will be required in the first place.

There is probably no benefit to the added flexibility of the 61 stranded catenary wire compared with the 37 stranded wire when supporting the contact wire in Overhead Wiring.

Anyway …

Figure 47 shows some arcing damage to a 270mm² catenary. Fortunately, the strands are the thicker size, since the conductor has 37 large strands, and the main damaged strand is still intact (although very damaged). It is very likely that a catenary with smaller stranding would have broken and unravelled several strands in this case. Note the blobs of molten copper and black burn marks, which are typical signs of arcing damage.

Figure 47 - A 37-stranded (270mm²) Catenary Wire showing arcing damage

Catenary *sag* is the *vertical* height difference at exactly *midway*, between the catenary wire and a straight line connecting adjacent catenary support points, as shown in *Figure 48*.

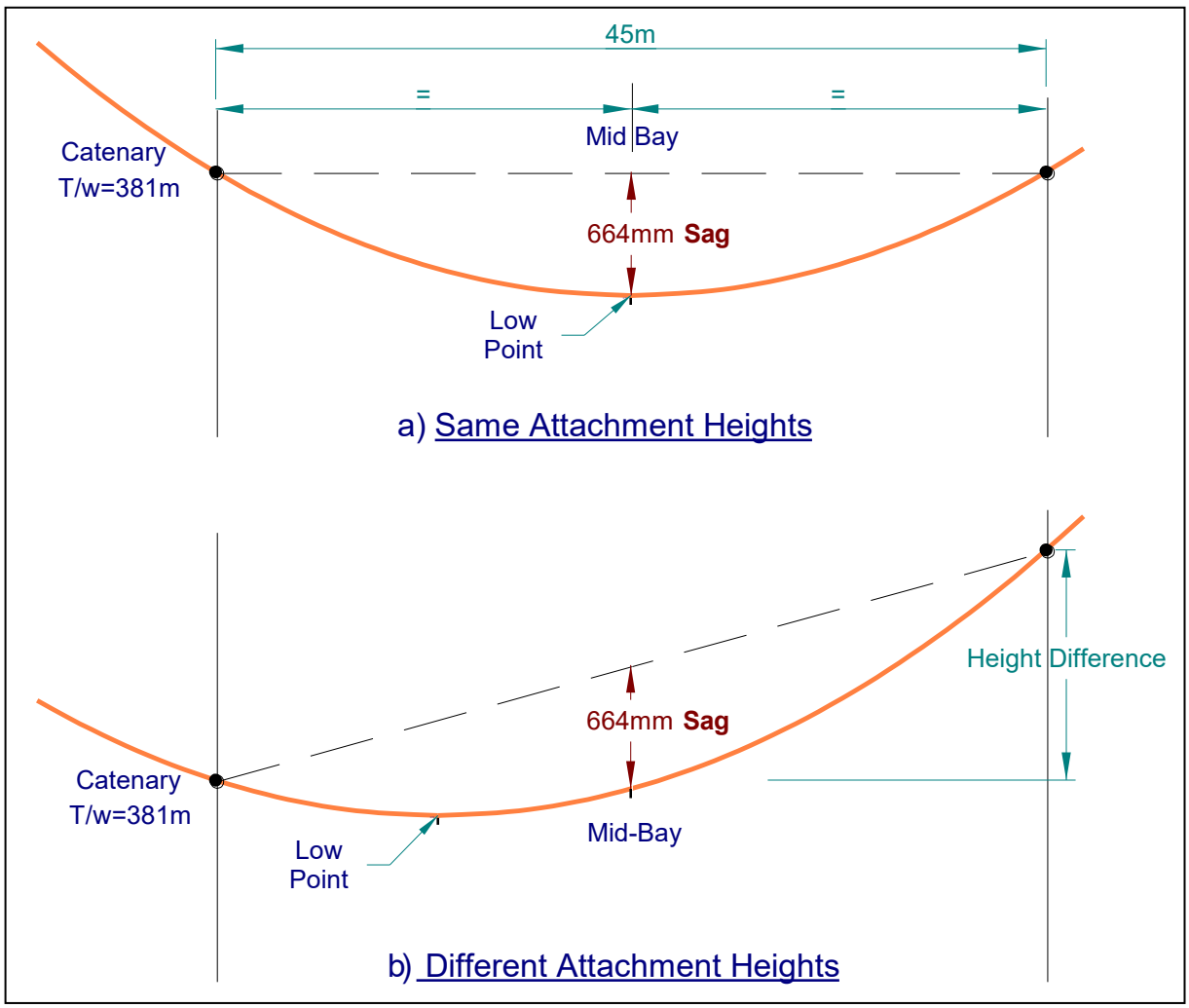


Figure 48 - Same Sag for same Bay Length

Figure 48 also shows an interesting characteristic of a parabola – that the same bay length gives the same catenary sag regardless of catenary attachment heights. This is good, as it makes it easier to calculate things like simple dropper lengths, which would otherwise need to always take into account track grade.

However, if the contact wire is not level throughout the bay e.g. installed with presag, then the redistribution of its weight supported from the catenary via the droppers, makes the accurate

calculation of dropper lengths much more complex, and this situation should be modelled using the appropriate dropper computer program. (In this situation, more contact weight is supported by the catenary towards the ends of the bay and less at the middle of bay.)

Also, note that the *low point* of the catenary shifts in a direction away from the point of higher attachment, as shown in *Figure 48 (b)*. This location is important to know, as the weight of the OHW supported at each of its 2 support points is equal to the weight of catenary (supporting the contact wire, droppers, in-span feeders, etc.), from the *catenary low point* in the previous bay, to the same in the next bay. For a greater appreciation of what this means, refer to *Figure 191* further on in *Section 3.2.0.5*, *OHW Loadings on S&R Arrangements*.

There's more about this below and in *Section 3.1.3* regarding *droppers*.

3.1.1.5 Design Notes

Catenary Tension

The actual tension in the catenary wire varies slightly depending on its location in the bay, but what remains constant at each point throughout a bay is its *horizontal* tension component (otherwise the wire would want to move to a new equilibrium point).

The wire tension is the vector sum of horizontal tension and the weight of wire at that point. At the catenary low point in the bay there is no weight component, so the wire tension here is purely the horizontal tension.

Catenary Sag

A tensioned conductor supported at two ends will exhibit a droop in the middle – termed *sag* (gravity does the work). In OHW designs, sag is always measured vertically.

In most cases, sag is undesirable as it places limits on the length of bays. The typical maximum bay length for OHW is about 70 metres or so, giving a sag of about 2 to 3 metres.

However, there are a few situations where a large sag can be beneficial, e.g. if the OHW passes under a footbridge without the need for being attached to the bridge (*unattached*), it can provide a better system depth at adjacent support & registration locations for suitable cantilevers to be installed. (Unattached also brings big benefits to the situation in other ways.)

On straight track the current maximum bay length is standardized at 67m (which then has some provision for slightly longer bays later on in case a replacement support mast ever needs to be installed next to an existing one – usually 1m or 2m away). The 67m figure is also limited by the maximum amount of contact wire "blowout" (with wind) in a bay – see later.

The simple fundamental formula for sag is as follows. (When supporting a contact wire, this formula is accurate provided the contact wire is supported evenly from the catenary wire, i.e. a flat contact wire with evenly spaced droppers.)

$$S = \frac{w\,L^2}{8\,T}$$

Equation 1 - Catenary Sag

Where,

S = Sag of Conductor (m)

w = Linear Weight of Conductor (N/m)

L = Length of Bay (m)

T = Tension of Conductor (N) [*Note:* this is the horizontal tension]

This formula is only relevant where the Sag is < 10% of the bay length, which is always the case with OHW conductors. This is fortunate as it is a simple equation (unlike with HV Aerial Lines, where the above condition is not always true, and which therefore requires the more complicated *hyperbolic "cosh" equation* to be used).

The catenary's shape is determined by its horizontal tension divided by its linear weight – its ***T/w*** value (in metres). Note that this is the inverse of what's shown in *Equation 1*. This has been done because it's easier to remember an integer than a decimal – e.g. compare the value *T/w* = 381(m) to its equivalent *w/T* = 0.00262(per m).

The higher the *T/w* value, the shallower the sag in a bay. In fact, the *T/w* is normally standardised at a set value for a wire system used in any project.

The *T/w* value is different for an *unloaded* catenary, i.e. before the contact wire is run and supported from the catenary from droppers (making it then a *loaded* catenary). For example, the current standard OHW system for open routes is System 2, which has a regulated catenary tension of 30kN. If this is initially unloaded (i.e. not supporting any contact wires below), then its *T/w* value is 1,252m. However, when the twin contact wires are subsequently supported, its *T/w* value reduces to 588m (becoming a deeper parabola with more sag as expected).

Most other current standard OHW systems use a slightly smaller loaded catenary *T/w* of 550m. Refer to *Table 7* (further back).

TENSION CHANGES

In the design process, any *fixed-anchored wire* needs to be carefully dealt with, because its tension can suffer greatly from temperature changes away from the design value (which in the past was 21°C).

This *tension change* phenomenon has to do with how often the wire is freely supported (allowed to move longitudinally) throughout the wire run, so it is not necessarily a constant value from start anchor to end anchor locations.

The measure of this phenomenon is its *virtual span* (VS), which is a mathematically derived number (in metres) – see *Equation 2* below. This aspect is covered to greater detail in document GL E 73002, "Understanding Virtual Span".

VS is a bit like an "average" support spacing. Unfortunately, its calculation can be quite involved, but is necessary in order to solve the complex temperature/tension equation.

$$VS = \sqrt{\frac{(L_1^3 + L_2^3 + \ldots\ldots + L_n^3)}{(L_1 + L_2 + \ldots\ldots + L_n)}}$$

Equation 2 - Virtual Span

Where:

VS = Virtual Span (m)

$L_1, \ldots, L_n$ = Consecutive bay lengths from catenary support to catenary support, starting from where it is "locked" and ending where it is again locked. (distances in metres).

Note: Because the VS figure applies between where the conductor is *locked* (fixed) from moving longitudinally, to where it is again *locked* from moving, there can be several VS values in a catenary wire run from end anchor to end anchor.

Example:

From *Figure 49*, consecutive bay lengths from where the catenary is locked are 50m, 30m, 30m, 30m, 50m and 67m, then the catenary is again locked from any wire movement.

Here, $VS = \sqrt{\frac{(50^3 + 30^3 + 30^3 + 30^3 + 50^3 + 67^3)}{(50+30+30+30+50+67)}}$

= **49.58m**

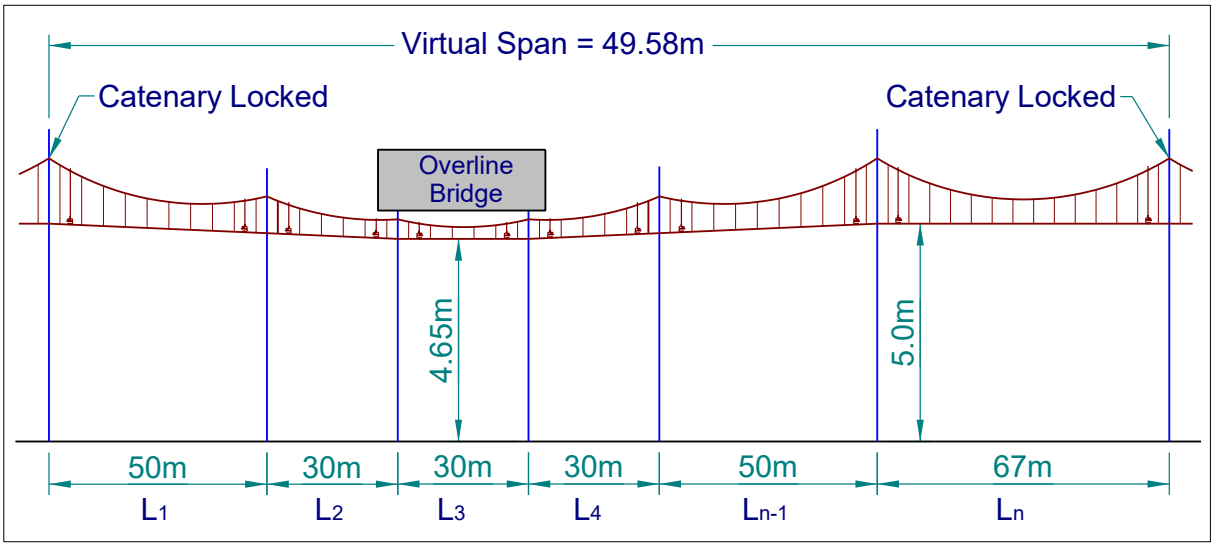


Figure 49 - Typical "Virtual Span" zone

In summary,

> *the smaller the **virtual span,***
> *the greater the **tension change** in response to a **temperature change**.*

A catenary wire can have a virtual span ranging from 20m or less (inside tunnels) to 73m or greater (in the open route).

Table 14 below shows the tension change as a function of temperature and for 2 different virtual spans – 60m and 20m. Note how badly the catenary wire tension suffers with temperature change when the virtual span is small (20m) contrasted with the larger (60m) VS. Note that the situation in *Table 14* is a 270mm² catenary wire supporting twin contacts (OHW System 28) with a design catenary tension of 19.43kN at 21°C. This is the OHW system installed in the Eastern Suburbs Tunnel.

	Catenary Tension (kN)		Total Tension Change	
Virtual Span	**At 55°C**	**At 0°C**	**Tension** (kN)	**% of Design Tension**
60m	16.07 (17% lower)	22.53 (16% higher)	6.46	33%
20m	10.20 (48% lower)	29.24 (50% higher)	19.04	98%

Table 14 - Typical Temperature / Tension relationship for Fixed-Anchored Catenary Wire

So, with a larger virtual span, a catenary wire can be better behaved under temperature extremes (i.e. remain closer to the design tension), which is always a good outcome, and is what designers strive for.

Note that, in the old fixed-anchored OHW, the designers of the OHW understood this issue quite well. Even around tight curves they maintained very long 73m bays, in order to better control the catenary tension. And to ensure pantograph security around these track curves, they had 1, 2 and sometimes even 3 pull-off arrangements equally spaced throughout the bay, to control the blowout.

It turns out that increasing the conductor's sag plays an important role in reducing the tension change with temperature. See *Section 3.1.2.5, Contact Wire Tension* for details of why this is so.

TEMPERATURE/TENSION CURVES

Figure 50 shows how virtual span affects the tension behaviour of a typical catenary wire – again the Eastern Suburbs Tunnel OHW is used in this example.

This graph reveals the true nature of *virtual span* and how it influences conductor *tension*.

The splayed lines each represent a conductor temperature – the left-most line is 55°C and the right-most is 0°C (in 5C° increments). Virtual span is shown on the left axis ranging from 20m at the bottom, to 60m at the top. The bottom axis shows the corresponding *tension* for that particular temperature & virtual span combination.

The main point of showing this graph is to demonstrate the *change in tension* of the catenary wire with a *small virtual span* (20m VS yields tension change = 19kN) compared to the same catenary with a *large virtual span* (60m VS yields tension change = only 6.5kN).

So virtual span can make a huge difference to the tension, and that's why it needs to be calculated each time for any OHW when fixed-anchored – and there can be several values of VS in a catenary wire run (depending on where it's locked from any longitudinal movement).

Note that, on the other hand, the fixed-anchored contact wire is regularly supported (by droppers) throughout the wire run, and it normally has only one value of virtual span – typically 4.57m. This makes things much simpler – for instance, instead of a graph (as above), a simple table can be used to show the temperature/tension relationship.

As one might expect, it is extremely important that the tension changes of the catenary (and contact) wire/s are properly handled in the design process. The extreme tensions need to be determined, and their consequences should be suitably controlled to prevent unwanted outcomes, which can include:

- Reduced wire *electrical clearances*, to overline bridges (above the catenary wire) in cold conditions, and top of train (below the contact wire) in hot conditions. In both cases at least 150mm minimum electrical clearance is required (and sometimes more than this is needed – refer to the Standards).
- Reduced *mechanical clearances*, such as vertical clearance of contact insulator skirt from pantograph, etc.
- Increased wire *blowout* with high wind speeds in hot conditions, risking *pantograph security*.
- Poor *pantograph dynamic performance* particularly at higher speeds, again in hot conditions. There's more on this later in the document.

Note that a "simple" excel spreadsheet was developed to generate both the Loaded and Unloaded "charts" shown here. This tool allows different scenarios to be readily modelled.

OHW Configuration Details

Catenary

Material :	Hard Drawn Copper
Area (sq.mm.) :	270
Weight (N/m) :	23.97

Contact

Material :	Tin-Bearing Copper
Area (sq.mm.) :	2 x 137
Weight (N/m) :	2 x 11.87
Tension (N) :	2 x 9,710

System Details

Tension (N) :	19,431
Weight (N/m) :	51
T/w (m) :	381
E (pa) :	1.24E+11
Alpha (per °C) :	1.70E-05
Temp1 (°C) :	21

Catenary Mode

Loaded or Unloaded ? :	Loaded
Weight (N/m) :	51

Virtual Span (m)

Maximum :	60
Minimum :	20

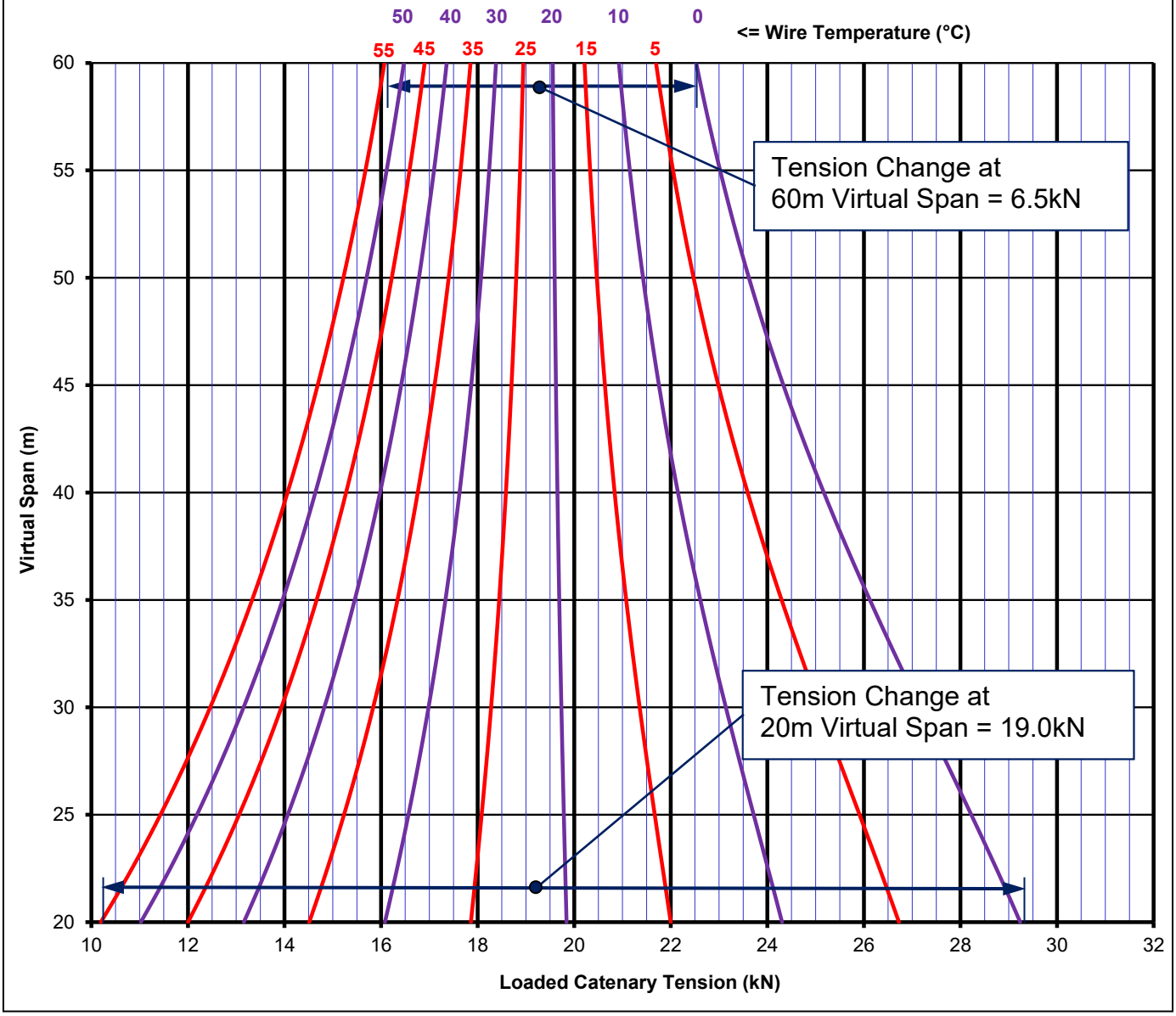


Figure 50 - Typical Temperature / Tension Chart for "Loaded" Catenary Wire

"UNLOADED" VERSUS "LOADED" CATENARY

When new OHW is being installed, initially the catenary wire is run from anchor to anchor and is configured as a fixed-anchored system, i.e. the tension regulators, if used, are locked from movement. This wire is then tensioned to a much higher value than its design tension – *super-tensioned* – for a length of time, in order to let the catenary strands stretch and settle in, and to remove any initial creep in the copper strands.

Before the catenary is dressed (with droppers and in-span feeders) and the contact wire is run, the catenary tension is lowered back to its "Unloaded" or "No-Load" tension for the current temperature. This tension is determined by reference to its *Unloaded* or *No-Load Temperature/Tension Chart*, which is a very clever graph, as explained below.

Knowing the virtual span of the catenary wire and the current wire temperature, the chart reveals the resulting no-load tension to apply to the catenary wire in this temporary fixed-anchored state.

Refer to *Figure 51* for the corresponding *Unloaded* version of the Temperature/Tension Chart of the Eastern Suburbs Tunnel OHW system. The shape of the family of curves is quite different to those of the *Loaded* curves in *Figure 50*.

This catenary tension is less than the final design tension, but it is such that, when the contact wire is run and held up from the catenary wire by droppers, the catenary will then be *Loaded* and be at its (higher) design tension for the current temperature.

Whilst remaining fixed-anchored, any adjustments to the tension of the Loaded catenary can be made by referencing the *Loaded Catenary Temperature/Tension Chart* from then on (if needed) e.g. *Figure 50*.

Of course, if the system is regulated, then releasing the weight tensioners will bring the catenary tension to its final regulated tension value, which is then independent of temperature. So, neither of the above charts are then relevant.

Note that these days, computer programs used on-site can help determine tension from virtual span and temperature, without the need for the Temperature/Tension Charts. However, these charts tell you everything you need to know, they are in a portable format, and they provide the necessary information without needing batteries!

CATENARY STAGGER

It is possible to position the catenary wire at the (superelevated) centreline of track at each support location, and apply the required stagger to the contact wire only. After all, it's the contact wire (not the catenary) that requires the necessary stagger at each location – for reasons of *pantograph security* and for promoting more even *wear* on the pantograph carbon strip collectors.

Having zero catenary stagger at each support location may seem a good idea, especially as it would allow easier calculation of each support (cantilever). However, it would lead to other complications – particularly where 2 wire runs interface in an overlap bay and both catenary & contact wires of each run need to be horizontally separated from the adjacent run by about 300mm throughout this bay, for electrical sectioning clearance.

Having said the above, in Sydney's OHW design, in order to eliminate any complications, it is policy that *the catenary wire is always located vertically above the contact wire*. In which case, the catenary can be considered as having the same *stagger* as the contact wire.

CATENARY BLOWOUT

The catenary can undergo wind *blowout* within each bay without generally causing too much concern. The amount of blowout is usually a similar amount to that of the contact wire supported below in a regulated system.

The main problem with catenary blowout is that the wire in its blown-out position needs to remain electrically well clear of nearby objects, as well as other electrical sections, to avoid arcing damage or livening nearby equipment.

OHW Configuration Details

Catenary

Material :	Hard Drawn Copper
Area (sq.mm.) :	270
Weight (N/m) :	23.97

Contact

Material :	Tin-Bearing Copper
Area (sq.mm.) :	2 x 137
Weight (N/m) :	2 x 11.87
Tension (N) :	2 x 9,710

System Details

Tension (N) :	19,431
Weight (N/m) :	51
T/w (m) :	381
E (pa) :	1.24E+11
Alpha (per °C) :	1.70E-05
Temp1 (°C) :	21

Catenary Mode

Loaded or Unloaded ? :	Unloaded
Weight (N/m) :	23.97

Virtual Span (m)

Maximum :	60
Minimum :	20

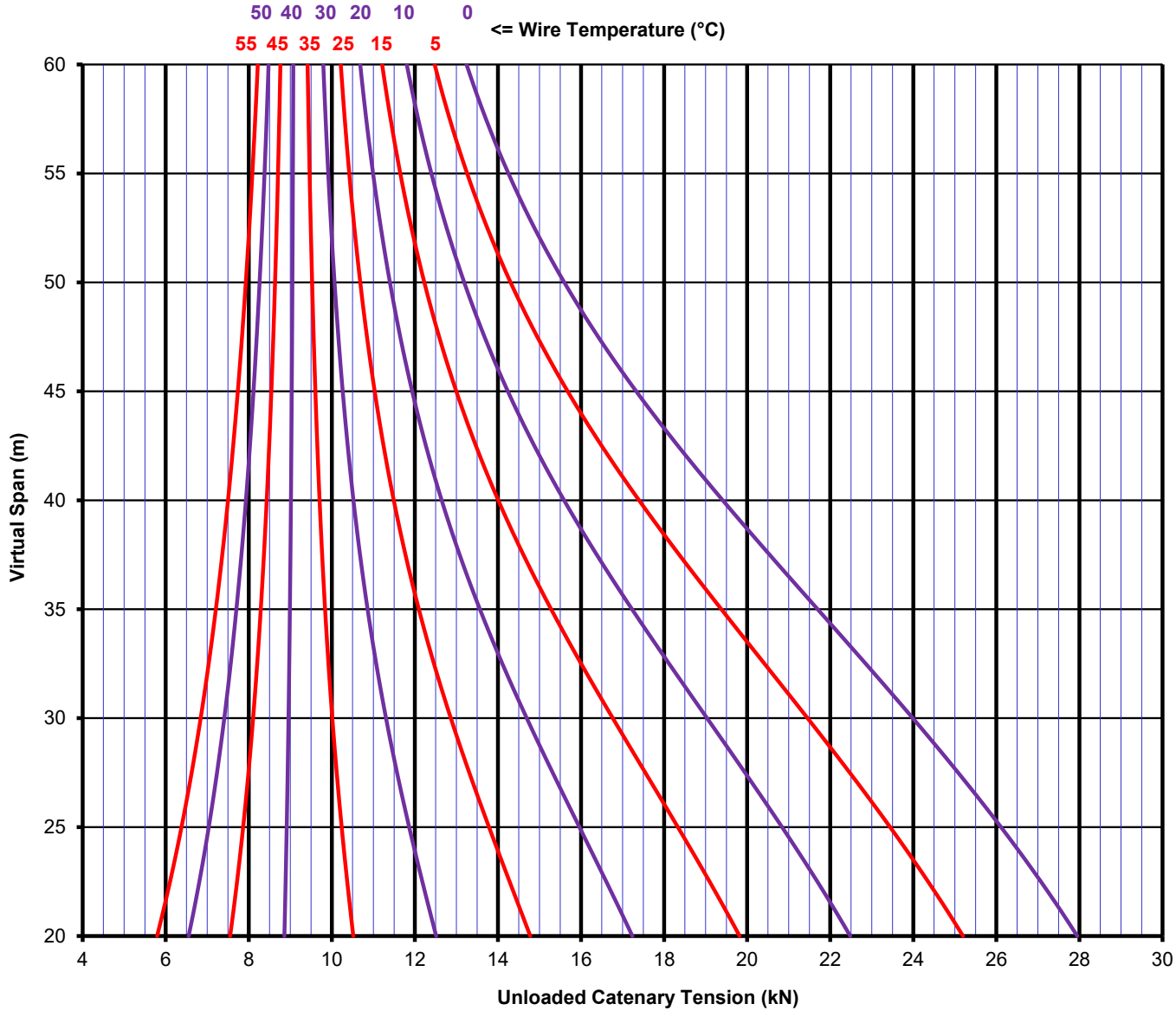


Figure 51 - Temperature / Tension Chart for "Unloaded" Catenary Wire

CATENARY HEIGHT

The height of the catenary at each support & registration location should be high enough so that, in each of the 2 adjacent bays, the catenary can sag and hold up the contact wire at its nominated height, with droppers of suitable length (the minimum dropper length is about 100mm). This is especially critical towards mid-bay.

The catenary should also not be set too high, as this would require very tall masts, and longer droppers and in-span feeders, i.e. mostly for economic reasons.

So, where practical, the catenary height is normally set somewhere in between, to allow for some contingency measures, should something need to be adjusted in the future.

There are a few scenarios, as detailed below.

Open Route

Standard catenary heights are given for the various standard OHW systems in use when in the open route, so that the designer mostly doesn't need to think about changing the catenary heights, except for the situations below (and maybe others). For example, Gosford to Newcastle had a standard catenary height of 7.3m (with standard contact height of 5.2m).

The current standard catenary height for all new regulated OHW systems is 6.5m (with 5.0m contact height). On long 67m bays, this system depth still results in reasonable length droppers at mid-bay, which is good (if adjustments are needed later on for whatever reason).

Approaching Overline Bridge or Tunnel

Catenary heights are generally lowered for the first 1 or 2 OHW support locations on both sides leading into a low bridge or tunnel.

The contact wire is usually lowered also to fit beneath the catenary under the (normally low) bridge or tunnel, and still be well above the absolute minimum contact height allowable (4.57m) for clearance to the top of a train. Again, the minimum dropper length needs to be factored in.

Inside Tunnels

Catenary heights inside tunnels are a different matter, unless the tunnel ceiling is so high as to not restrict the catenary placement.

Most tunnels are designed with the bare minimum heights that would allow the train as well as some form of OHW system to be installed to power it. Most tunnels also have curved linings in the area above the train. In this case, the catenary is supported from its insulator with a bracket installed onto the tunnel lining, often with little or no room for catenary height adjustment (e.g. refer to *Figure 516* and *Figure 519* further on for an idea of what this means).

If they have a uniform height above track, flat ceiling "tunnels" can provide for a more consistent catenary height. For example, a 6m ceiling height above track might allow for a 5.7m catenary height using a post type insulator (and 4.75m contact height), but the as-built catenary height might be a little different from this figure. A field survey of ceiling height at each proposed S&R location is crucial in this situation.

To give an idea of the nature of some tunnels, the twin-track tunnel for the Airport Line had a mix of "breadloaf" (with several slightly different shapes), circular (from the tunnel boring machine) and flat roof tunnels, throughout its length.

Level Crossings

These typically require a very high contact height to clear the road traffic, and this often necessitates the catenary height to be increased slightly.

Refer to *Section 6.4.5* for more details.

THERMAL PERFORMANCE

A train's heavy load current passing through the OHW causes the catenary and contact wire temperatures to rise.

It is unfortunate that the bigger the conductor cross-sectional area, the harder it is to dissipate any stored heat within the conductor.

Over the past 20 years or so there has been a deliberate shift away from the larger 327mm² and 510mm² copper catenary wires, because of their relatively poor thermal efficiency performance.

As was explained in *Section 3.1.0.5*, *Thermal Aspects of OHW*, the OHW conductors need to cool down as quickly as possible after a train passes, ready for the next train to again heat them up.

Indeed, it appears that in order to get the most efficient OHW system in terms of current-carrying capacity, the catenary size should be reasonably matched to the contact size.

In this regard, the 165mm² and 270mm² catenary wire sizes are a better match for the 137mm² and 193mm² contact wires. This goes for twin contact as well, and for twin catenary configurations too. Unfortunately, 327mm² and 510mm² catenary sizes are just too large to be effective with these much smaller contact sizes.

In other words, you can get more value out of the copper by matching sizes – any larger size can be seen as a waste of copper, since it cannot work as hard (pass as much current density).

The larger copper sizes also require higher tensions in the conductor to keep it up in the air. This translates to higher mechanical loads imposed on the OHW support structures and anchor structures, and to cope with the loads, they may need to be made a larger size (e.g. 250 UC becomes 310 UC) or thicker gauge steel (e.g. 250 UC 72.9kg/m becomes 250 UC 89.5kg/m), which can also be wasted money.

The conductor temperature rise can result from a train demanding heavy current from the OHW, and also importantly these days, from current generated back into the OHW by regenerative braking onboard trains that can help feed any nearby trains.

Note that, if more copper is needed in the air (e.g. to lower the circuit resistance for DC circuit breaker protection), then more conductors may need to be run in parallel. So, employing a twin catenary / twin contact OHW system may be of benefit here.

CARE WITH CROSSING CATENARIES

If 2 catenary wires cross close to each other, in such a way that one wire could momentarily touch the other, or rest on it for a period, then this can create arcing and burning of the vulnerable outer strands of both catenaries, as current tries to feed between them. This risks one or both catenary wires losing strands or annealing and ultimately snapping under the tight mechanical tensions, bringing the OHW down and stopping trains.

Even though this situation of crossing catenaries seems harmless enough, and sometimes isn't even considered, the fact that Sydney's OHW system demands lots of current – from anywhere it can get it – means that this type of situation should be avoided at all costs.

And this is a potential problem even if the 2 catenaries are in the same electrical section!

This complication is particularly relevant to fixed-anchored OHW, where the catenary sag changes with temperature. If one catenary has a different sag or tension profile to the other, then the 2 wires with small clearance (such as 100mm), could possibly touch at certain temperatures, more so if this occurs well out in the bay (where the catenary heights are much less well controlled). And wind, causing the wires to move laterally, can further exacerbate the problem as these wires touch. Pantographs can cause up and down movement too.

There are a few approaches to this problem, and I list the 4 main ones below:

- *Provide plenty of clearance* between these 2 wires – at all times. This is likely the simple, preferred approach. The design of such a situation should set appropriate catenary support heights to ensure plenty of clearance – all the time. Something like 300mm or more clearance may be necessary, subject to the design requirements at that location.
- *Mechanically tie the 2 catenary wires together*. This forces the wires to behave, with no intermittent arcing or burning. There are at least 2 situations here too.
  - This could involve using an appropriate U-bolt clamp for the 2 wire sizes. The copper-to-copper feeding would need to be checked out in its design. In the case of steel catenary crossing copper catenary, they used to install an insulated tube over the copper before clamping it to the steel catenary using a U-bolt clamp. But even this situation needs to be designed properly, to make sure the accompanying altered Virtual Spans don't cause problems elsewhere in the 2 affected wire runs. (This situation with steel catenary is discussed further below.)
  - Otherwise, an insulated knuckle of suitable length could be installed to help control (force) how close these wires can come together. Again, this would need to be properly designed and installed.
- *Electrically tie the 2 catenary wires together*. This probably applies more to regulated OHW where the catenary wires move longitudinally relative to each other. Install a U-shaped feeder jumper adjacent to where they cross, but configured such that the clamps cannot interfere with each other and snag.
- *Install a pennant insulator and potential jumper*. This is the situation in the standard regulated OHW overlap arrangements, where the out-of-running catenary crosses the in-running catenary when heading off to anchor. The clearance between catenaries where they cross is typically only 50mm, so the pennant insulator allows the OOR catenary to be the same electrical potential as the IR catenary, and they are electrically tied with a potential jumper (since there is then no chance of feeding any significant current).

Note:

Any attempt to mechanically tie the catenaries together will result in loss of Independent Registration, which may not be acceptable these days.

Refer to *Figure 52*, which shows an unusual and awkward potential jumper arrangement in regulated OHW. It takes a while to understand what's happening here, which is a problem in itself! It's essentially a (strange) 90mm² potential jumper atrrangement, tying an otherwise floating section to the main OHW.

Figure 52 - Awkward Potential Jumper arrangement

Unfortunately, it may be possible for the relative longitudinal wire movement to cause the lower clamps to snag, then ...

But probably more importantly, any wire that touches another is likely to take some electrical current and result in arcing or burning, particularly when the train is nearby.

It may take a while, but the intermittent contact of the flimsy 90mm² potential jumper loop against an adjacent wire, and causing arcing, may eventually result in the main highly-tensioned wire becoming so damaged that it snaps and brings the OHW run (or runs) down.

This situation should have had the simple standard U-shaped potential jumper, located further away from the crossing point to be out of the way, and a simple in-span feeder connecting OOR catenary to its OOR contact pennant wire below it. Easy to understand for everyone who patrols this area.

In summary, any arcing or burning of the catenary wire/s is the problem that needs to be anticipated and avoided.

WIRE STRANDING

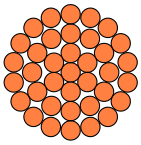
Unlike the contact wire, the catenary wire is a multi-stranded conductor, and its stranding composition depends on the number of individual wire layers built up over a central wire. Knowing the number of layers also allows its overall diameter to be determined, as given in *Table 15*.

Note that each additional layer adds 6 more strands to the number in the previous layer. Compare the makeup of strands of the two 270mm² catenary sizes shown to the right of the table (the 37 strand version is the current standard wire).

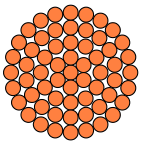
No. of Layers	No. of Strands	Stranding Layer Configuration	Diameter of Conductor (mm)
0	1	1 (solid conductor)	1 × Ds
1	7	1 / 6	3 × Ds
2	19	1 / 6 / 12	5 × Ds
3	37	1 / 6 / 12 / 18	7 × Ds
4	61	1 / 6 / 12 / 18 / 24	9 × Ds
5	91	1 / 6 / 12 / 18 / 24 / 30	11 × Ds

D_S = Diameter of each strand (mm)

Table 15 - Wire Stranding composition



270mm²
37x3.05mm strands
3 Layers



270mm²
61x2.36mm strands
4 Layers

The format of the simple wire stranding used for OHW includes the total number of strands and the diameter of each strand, e.g. "37x3.05mm". (More complex stranding composition is used in other areas, e.g. see *Section 3.4.2.5*, *Wire Rope* further on.)

I understand that Sydney's OHW policy has been for all conductors to have the outer layer wound as right-hand lay (i.e. the strands spiral clockwise as they head away from you). All successive layers back to the centre are each wound in opposite directions.

LOCATION OF AUXILIARY FEEDERS

Auxiliary feeders are wires added in parallel (electrically and usually physically as well) to the main catenary wire. Doing this can help in 2 ways:

- It reduces the electrical circuit resistance, and
- It increases the current carrying capacity of the OHW (which can help prevent the associated conductors from overheating).

For many decades, the policy has been to locate any auxiliary feeder over trackwork. Apparently, this was done so that if this conductor snaps or its support fails and causes the conductor to fall, it would more than likely touch the rails of a track, causing heavy current to flow and tripping supply (opening DCCBs), thus rendering the circuit safer, and importantly alarming the Electrical Operating Centre ("Elec Trouble") of a problem to be immediately investigated.

If the auxiliary feeder was to be located over land, then it is possible that a feeder dropping to ground (for whatever reason) could remain alive, which is a dangerous situation that should be avoided. (The protection scheme relies on either heavy fault current or rapid rate-of-rise of the current in order to trip supply.)

Aside:

> Note that this is one benefit of 25kv ac traction systems (apart from the fact that auxiliary feeders would not be required in the first place) – the protection technology is superior in that it should be able to trip on "earth leakage" (as well as "overcurrent"). And "differential protection" may also be available to quickly render safe the scenario of a conductor falling to ground(?).

If an auxiliary feeder needs to venture across land away from the tracks, then installing the feeder as one or more screened cables could offer the necessary protection and avoid the safety issues of a damaged exposed live conductor at or near ground level. If this 1500V cable was struck, the surrounding copper screen of the cable, which should be connected to the negative return path, would allow the circuit breakers to trip the supply, which is a safer outcome (albeit at some initial expense).

If bare auxiliary feeders are installed over portal structures or OHW support & registration arrangements, these structures could ideally be spark-gapped in case the conductor fails. This would then help trip the DCCB protection to isolate supply. But this risk, in conjunction with the bonding policy, would need to be dealt with in that particular project. Refer to the current standards.

The first twin 270mm² regulated catenary OHW system was introduced in the 1993 as a way to use smaller catenary wires (less than 327mm²) with their better thermal performance. Just as important, it was also done to avoid the need for an independent auxiliary feeder, and by doing so, keep these wires always together and over a track, for the sake of improved safety and more reliable electrical protection.

AUXILIARY FEEDER CLEARANCES

Auxiliary feeders can be installed to both fixed-anchored and regulated OHW, although the auxiliary feeder itself would normally be tensioned as fixed-anchored as there's no point to having it regulated.

Where the auxiliary feeder is for strengthening *fixed-anchored OHW*, the additional sag (hot) or reduced sag (cold) conditions need to be considered in the design of the support for such an arrangement. This might affect clearances to nearby earthed objects, and the normal 150mm absolute minimum electrical clearance requirement needs to be met, even with 130km/h wind blowing.

If the auxiliary feeder is for strengthening *regulated OHW*, then clearances relative to the longitudinal wire movement of the regulated wire needs to be taken into account. This means confirming suitable electrical clearances are maintained to items such as adjacent cantilever pipes, even with 130km/h winds and with cantilever frame swinging one way or other when the wire expands or contracts.

STEEL CATENARY

Steel catenary was used way back in time, in areas that did not require the supply of lots of current. This meant areas of slow speed running, such as in various shunting yards and some crossovers. See *Figure 522* further on for a view of steel & copper catenaries side-by-side.

I understand that the steel catenary itself was not intended to carry any load current, and so any droppers supporting contact wire were to be insulated from this catenary (e.g. using neoprene tubing) and there should be no in-span feeders.

Also, wherever a steel catenary crossed next to a copper catenary, they tended to clamp the 2 wires together. However, they installed an insulating sleeve over the copper catenary before U-bolt clamping the 2 together. This provided the necessary insulation to prevent any feeding current from passing through this mechanical connection.

Apparently, the load current could be handled by the contact wire by itself, and the steel catenary was there primarily to help control the contact wire's shape (sag), especially at mid-bay on hot days, so as to keep the wire well above the train roof. This outcome was probably deemed better than having the alternative contact-only OHW system (which required more frequent support structure spacing and which also resulted in deep sags at mid-bay, and necessitated very slow speeds).

There are normally many tracks running in parallel in shunting yards, etc., and using a small size steel catenary (with its reduced tension and weight loads) was likely a way of reducing the overall mechanical loads imposed on their corresponding multi-track support structures (portals, etc.), thus keeping costs down.

The steel catenary I'm aware of had 7 strands only. These strands would have been initially galvanised, but over the decades this coating has progressively disappeared, eventually showing the brown signs of surface rust to varying degrees instead.

The main concern with the steel catenary is whether there's any significant corrosion taking place within the wire bundle itself. The corrosion aspect may have been the reason why there are only 7 strands – 6 outer strands and only 1 internal strand – as this will limit the amount of any internal corrosion.

Steel catenary has not been used for any projects over the past few decades.

More information on steel catenary is given in *Section 4.1.7, Steel Catenary in Yards*.

3.1.1.6 Status (c. 2014)

Current standard catenary sizes are:

- 165mm²
- 270mm²

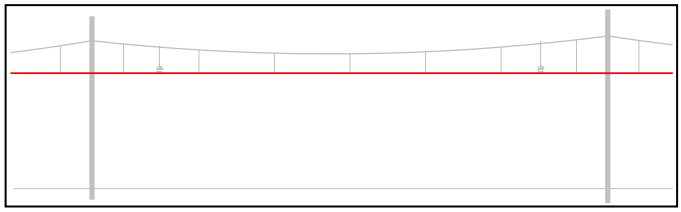
Steel catenary is no longer to be used because it is not intended to carry current (thus forcing the contact wire to carry all the current). It also corrodes in time, leading to failures at unpredictable times (corrosion is often hidden under installed fittings such as dropper clips).

Currently only the 165mm² and 270mm² catenaries are used for future electrification works. However, the other copper catenary sizes may still be used for minor alteration works to match any existing OHW.

3.1.1.7 Reference

Standard catenary sizes and characteristics are shown in SRA drawing D/88336.

3.1.2 Contact Wire



3.1.2.1 Description

The contact wire is a solid hard-drawn copper wire that is located beneath the catenary wire (if present). It is extruded as a single strand, 14 to 16mm in diameter, and has a specially shaped groove at the top of its section which is intended for connecting clamps to it in a way that keeps them clear of passing pantographs.

A train's several pantographs push up against the underside of the contact wire and slide along it, to pick up the electric current which feeds the electrical energy needs of the train at about 1500 volts.

The contact wire is the most important component in the OHW system.

This importance is because it directly interfaces with the train as it supplies power to it, which is the whole point of the OHW system.

In the majority of OHW systems, the contact wire is supported by regularly-spaced droppers from the catenary wire above it. Note that it is never supported by a dropper at a catenary support location. (Refer to *Section 3.1.3.5*, *Location of Droppers* for the reasons).

The contact wire is one of the few components in the OHW system that *wears*, due to frictional contact with the moving pantograph sliding under it. However, the wear *rate* is very low as the pantographs include special carbon strips that make the physical sliding connection with the copper contact wire, and this interface dramatically reduces any frictional wear.

This wire is also one of the most vulnerable OHW components to being damaged, because it's located very close to the top of a train and in direct mechanical connection with the train's several uplifted pantographs. When it wears, it develops a flat underside surface consistent with the pantograph connection.

3.1.2.2 Function

The contact wire performs the following functions:

- It directly feeds electric current to the train's pantographs.
- It provides a mechanically continuous overhead path, with a flat or near-flat profile for smooth and uninterrupted pantograph current collection, even at high speed.
- The contact wire has sufficient weight, and is designed to be under enough tension, to effectively limit any significant pantograph *uplift* (this is localised upward movement resulting from each pantograph's upward vertical force of about 130N).

For most of the wire run, the contact wire is *in-running*, meaning that it is in contact with the train's pantographs as it passes through. It will eventually go *out-of-running* to anchor.

When in-running, the contact wire needs to be within certain *height* and lateral *stagger* tolerances of the track being serviced, so that it remains on, and controls, the train's pantographs. These are 2 essential requirements, even under all sorts of adverse conditions (such as high train speeds and vehicle sway, lateral track movement, extremely windy conditions, hot and cold temperatures, heavy rain and snow, etc.). A sudden change in height can lead to problems.

The requirement for it to remain on the pantograph is termed *pantograph security*. It enables uninterrupted current collection for powering the train, and it assures that the pantograph will

not suddenly rise up uncontrollably (which would otherwise then damage the OHW system and pantograph/s and ultimately stop trains for extended periods). Refer to *Section 6.3.2.2*.

3.1.2.3 Typical Components

(Not applicable.)

3.1.2.4 Configuration

For Sydney's OHW system, contact wires come in only 2 sizes: 137mm² and 193mm², (*Figure 53*).

In order to provide suitable interaction with the train's pantographs, contact wires need to be *tensioned* as high as practical. Using a metal with high tensile strength can help achieve the high tensions required here.

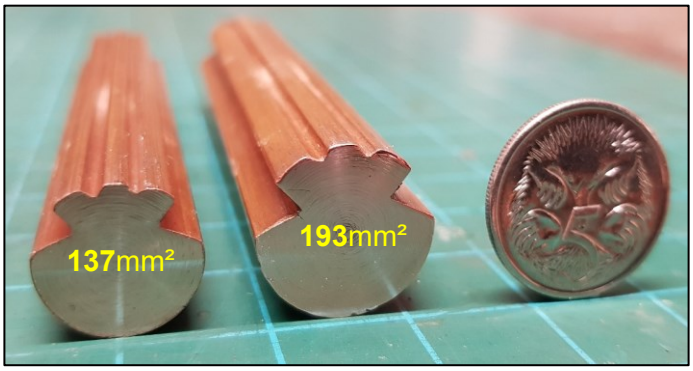


Figure 53 - The 2 Contact Wire sizes (diameters compared to a 5 cent piece)

Being made from 3 possible metals, there are thus 6 possible variations of contact wires, and these are listed in *Table 16*.

Contact Area [New] (mm²)	Contact Material	Diameter [New] (mm)	Weight [New] (N/m)	Breaking Load [New] (kN)	Reference Drawings
137	Cad-Copper	13.72	11.87	56.1	A4/45511/1
	Hard Drawn Copper	13.72	11.87	46.5	A4/45511/2
	Tin-Bearing Copper	13.72	11.87	54.8	A4/45511/3
193	Cad-Copper	16.41	16.89	73.3	A4/63998/1
	Hard Drawn Copper	16.41	16.89	58.8	A4/63998/2
	Tin-Bearing Copper	16.41	16.89	70.4	A4/63998/3

Note: [New] means condition when purchased.

Table 16 - Standard Contact Wire sizes & details

There are 2 main electrical things that the contact wire needs to achieve:

a) Allow the supply of *heavy current* (typically around a thousand amps) to the train without overheating, and

b) In conjunction with the catenary, provide a relatively *low resistance path* to the train at all times (and locations). This is needed

- To ensure that the substation's electrical protection (circuit breakers) will always "see" any *heavy current fault* and trip when required (to render the situation safer), and
- To help reduce any *voltage drop* from substation to the train itself, so the train voltage remains high.

A contact wire made from high-conductivity copper provides a good low electrical resistance path in this situation. However, in its typical state, copper is relatively soft. [The insulated copper wire used in most low voltage electrical circuits is annealed (softened) to provide good flexibility for easy installation].

To improve its strength, copper can be *hard-drawn* by forcing it through special dies. The process of drawing the copper through a die reduces its diameter and also *work hardens* it. Repeat this drawing enough times and the wire can be made extremely hard throughout its

circular cross-section. This then gives the solid wire a high tensile strength, as required for use in OHW.

To further improve the tensile strength of copper, other alloying metals have been introduced.

For Sydney, 2 alloying metals have been chosen for use in contact wires:

- ***Cadmium-Copper***. "Cad-Copper" (as it is referred to) has been used since the early days of electrification, although since about the 1980s it has no longer been used. This alloy metal was needed to cope with the extremely high tensions of a fixed-anchored OHW system under **cold** conditions. It has superior tensile strength, of the order of 21% to 25% stronger than just hard-drawn copper (see below). It is identified by the absence of any grooves in the top of the contact wire (as it was the original contact wire for Sydney).
- ***Hard-Drawn Copper*** (no alloys). This conductor is used in regulated OHW where the contact tension remains constant. It is not as strong as cad-copper or tin-bearing copper (below) but it has a lower resistance, which is good. It is identified by 1 groove in the top of the contact wire.
- ***Tin-Bearing Copper***. This has been used as a replacement for cad-copper in recent times (since about the 1990s), which was needed because apparently the cadmium chemical is hazardous during the manufacture of the cad-copper at high temperatures. While not as strong as cadmium, tin too provides vastly superior tensile strength, of the order of 18% to 20% above hard-drawn. It is identified by 2 grooves in the top of the contact cross-section.

Note that there are other metals available that have been alloyed with copper, such as silver, nickel, etc. Whilst some are popular overseas, none are as yet used in Sydney's OHW system.

The down side to alloying the copper is that the contact wire's electrical resistance normally increases (except if silver is added), and this can have adverse effects, including reduced spacing between substations, more ongoing resistive energy loss, etc.

So, within Sydney's system there are 6 combinations of contact wire sizes and metals.

Referring to *Figure 54*, identification grooves are provided on the top for:

- *Hard Drawn Copper* (single 0.5mm radius groove), and
- *Tin-Bearing Copper* (twin 0.5mm radius grooves).

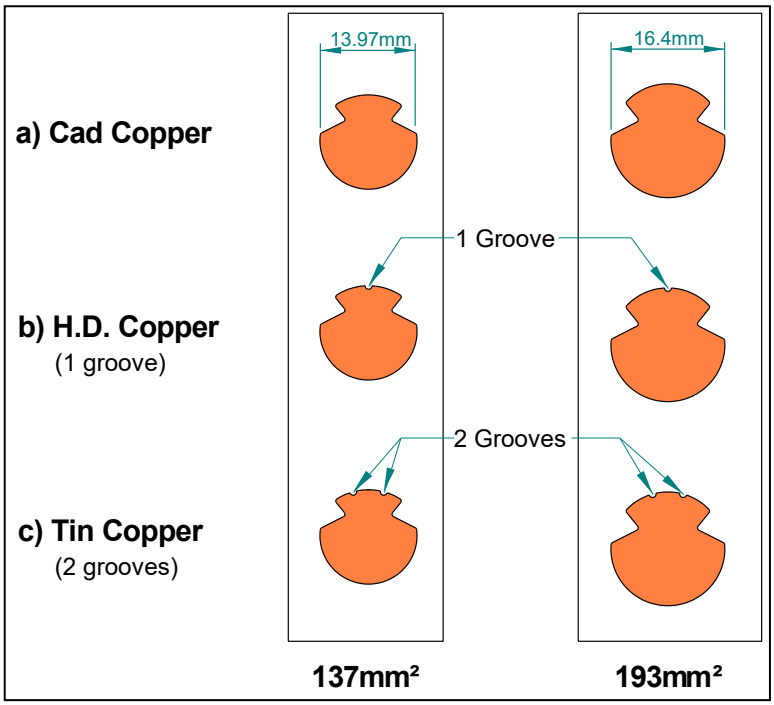


Figure 54 - Types of copper Contact Wire

Contact wires are extruded in a special die to form a single solid "bar" with two large wedge-shaped notches at the top. These notches are there for attachment to specially designed clamps, such as *contact swivel clamps* (for pull-off arm connection), *in-span feeder clamps* (for transferring current), etc. In this way the clamps can remain well clear of any pantographs passing below the contact wire.

TWIN CONTACT

In Sydney, an OHW system can be configured either with a single contact or with twin contacts.

Twin 137mm² contacts are spaced 50mm or 150mm horizontally apart in each bay.

Compared to single contact, a pair of wires offers a superior interface to the train's pantographs and so this configuration is preferred in all main line OHW applications these days. The reasons for this are listed below.

- The spacing between the twin contacts provide greater coverage on the carbon strips of a pantograph, resulting in *improved pantograph security*. (See *Section 6.3.2.2*)
- The additional contact weight can *more effectively deal with the large upward force of each pantograph*, which results in less vertical movement of the contact wires and so helps achieve higher train speeds. (It was also particularly important when 2, 3 or 4 locomotive freight train consists – each with 2 pantographs up – used to run in the electrified network.)
- They are more able to spread the *lateral wear on the pantograph carbon strips*, and with *less burning* of the contact wires if a localised poor connection is encountered (with 2 contact areas instead of just 1). This increases the working life of these carbon strips.
- They can provide a *higher current rating* by offering 2 connecting points on each carbon strip of each pantograph. This can be particularly important when the train is standing still for long periods, since passing the share of the train's auxiliary current in each stationary copper/carbon interface area means it's less likely to overheat locally when drawing this current. I guess this is most important with new contact wire, which will appear to the carbon strip as a single line (that is, until it wears a flat surface underneath which then yields more surface area which is a good thing to help spread the current load).
- *Improved thermal performance*. The normal single contact OHW system uses the larger 193mm² contact wire, whereas the twin contact system uses the smaller 137mm² contact wire size. As discussed previously, when the contact wire heats up under a train's heavy load current, the smaller wire can cool down quicker before the next train comes along, which is highly desirable these days.

CONTACT WEAR

In each bay, the weight of the contact wire counteracts the upward force of each pantograph on a train passing through, and with the relentless passage of numerous trains each day, this frictional sliding connection has to eventually lead to wear on the underside of the contact wire. This is shown as "vertical wear" in *Figure 55*.

As expected, the wear occurs on the bottom of the contact wire. (Actually, the wear should be in a plane parallel to the superelevated track.)

The exception happens at places such as "forking-in points" in some turnout situations. Here, the stainless steel horn (side edge) of an uplifted pantograph may rub against the side of the oncoming contact wire, in an area where these two parts eventually meet. This results in accelerated side wear over a relatively short distance of the contact wire. This "diagonal wear" is also shown in *Figure 55*. This is discussed further on in *Section 5.1.29*, *OHW Design at Turnouts*.

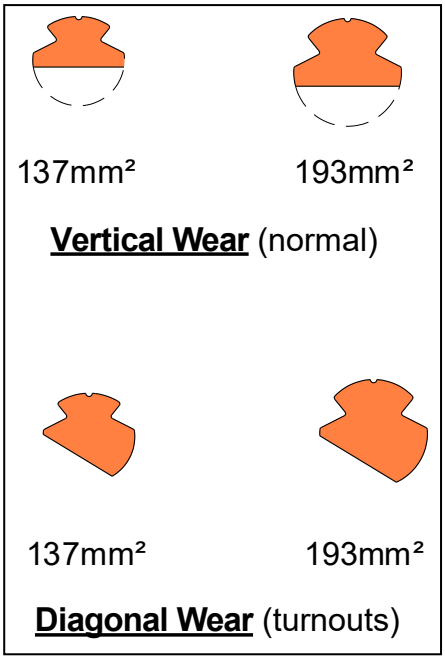


Figure 55 - Worn Contact Wire near Condemning Size

When a contact wire is new, the pantograph uplifts against a narrow *line* at the bottom of the wire, and this must place enormous localised stress on the carbon strips, especially as it passes many hundreds of amps. However. as the wire wears, the point becomes a flat strip *area*, which widens with further wear and helps ease the heavy-current stress on the carbon strip, and ultimately promotes better wear on them.

Eventually the contact wire can wear so much that its flat strip area almost reaches the full diameter of the wire, as shown in top view of *Figure 55*.

This amount of large wear usually takes many decades to occur in a wire run if it is under regulated tension (it can happen sooner with fixed-anchored OHW).

However, the wear can also occur over a much shorter period of time (e.g. weeks) in more localised places (termed *spot wear*), if the geometry of the contact wire was incorrect or had come out-of-adjustment, for whatever reason.

Sometimes a *hard spot* on the contact wire can lead to spot wear, e.g. caused by the downward pressure of a heavy pull-off arm, contact splice or a kink in the contact wire. *Figure 646* (towards the end of this document) shows a case of extremely thin wire, most likely at a contact full splice where the thickness is somewhat hidden and not obvious.

When the cross-section of the wire has worn uniformly over much of the wire run, the loss of wire weight and its possible detrimental interaction with uplifted pantographs should be considered, and action may need to be taken to prevent any adverse outcomes.

At some stage, a heavily worn contact wire must be renewed as it has reached its *condemning* size – see below.

CONDEMNING SIZE

Contact wires are normally allowed to wear down to a *condemning size* (wire thickness). See *Figure 55*.

The condemning size is such that it still has about 2:1 safety factor remaining under its highest anticipated tension. Refer to the applicable contact wire (size & metal) data sheet for details.

If the contact wire approaches the condemning size, it should be planned for one of the following corrective actions:

- Installation of a sacrificial wear strip to prevent further wear (if only spot wearing is evident),
- Splicing a new section of contact wire (if the wear is relatively localised), or
- Renewing the whole contact wire run (if uniformly worn).

For more information see *Section 3.1.2.5*, *Condemning Size*.

3.1.2.5 Design Notes

I repeat – the contact wire is the most crucial component of the OHW system.

CONTACT WIRE TENSION

In the design process, any fixed-anchored contact wire needs to be carefully dealt with, because its tension suffers greatly when temperature changes, and with a much greater magnitude than that of its supporting catenary wire.

As described previously, the value of *virtual span* (VS) in a portion of a wire run will dictate how much the tension changes with temperature in that wire. But unlike the catenary where the smallest VS is of the order of 20 to 30m, the fixed-anchored contact wire has a *virtual*

span of only about 4.57m (which approximates the distance between the fairly uniformly spaced supporting droppers over the run length). With a much larger virtual span, the catenary wire is better behaved, i.e. produces much less tension change than the contact wire.

Table 17 tells the story for the contact wire. Compare these values with the changes shown in *Table 14* for the catenary wire.

See also *Figure 56*, which is an equivalent *Temperature / Tension Chart* for the 193mm² contact wire tensioned at 13.35kN @ 21°C, in the bottom of *Table 17*. This chart is unnecessary, since the only VS figure of interest is the line that says 4.57m (although it could be used for the contact-only system in Sydney Yard, with its much larger virtual spans of about 30m?).

VS = 4.57m	Contact Tension (kN)			Total Tension Change	
Contact Size (mm²)	**At 55°C**	**At 21°C**	**At 0°C**	**Tension** (kN)	**% of Design Tension**
137	1.27 (86% lower)	9.34	15.05 (61% higher)	13.78	148%
193	1.87 (86% lower)	13.35	21.39 (60% higher)	19.52	146%

Table 17 - Typical Temperature / Tension relationship for the 2 Fixed-Anchored Contact Wires

Contact Versus Catenary Tension Change

So, why is there such a huge tension change with temperature for the fixed-anchored contact wire, compared to the catenary wire above it?

In a nutshell, *a conductor's sag directly influences the amount of tension variation that accompanies temperature changes*.

A wire expands when it's hot, and the extra length of wire has to go somewhere. It's a rather complicated formula that determines the changed tension when sag is involved. However, if that extra length can be mostly used up by providing more wire sag in the bay (following the sag equation), then there'll be less length involved in actually changing its tension.

In other words, if a hot conductor can take up its expanded wire length by sagging more, then this can help maintain closer to the original design tension.

Unfortunately, *the contact wire does not sag much* between its supporting droppers (typically only about 20mm sag when hot), so most of the extra length causes its tension change, and by quite a lot.

A bit more explanation …

A conductor lengthens when it gets hot and contracts when it cools (in a linear fashion).

A conductor supported between 2 points sags under the applied tension. Discarding any stiffness in the wire itself, the amount of sag is proportional to (*Bay Length*)². So, doubling the bay length gives 4 times the sag (which is measured vertically). Also, the more the sag, the longer the *length* of wire is taken up in that sag, according to its own formula (not given).

When a sagged conductor heats up, the extra length of the conductor has to go somewhere, so some of that length causes additional sag in the bay, and the rest of the length goes into tension change. If the wire sags a lot, it's able to maintain somewhere near its design tension.

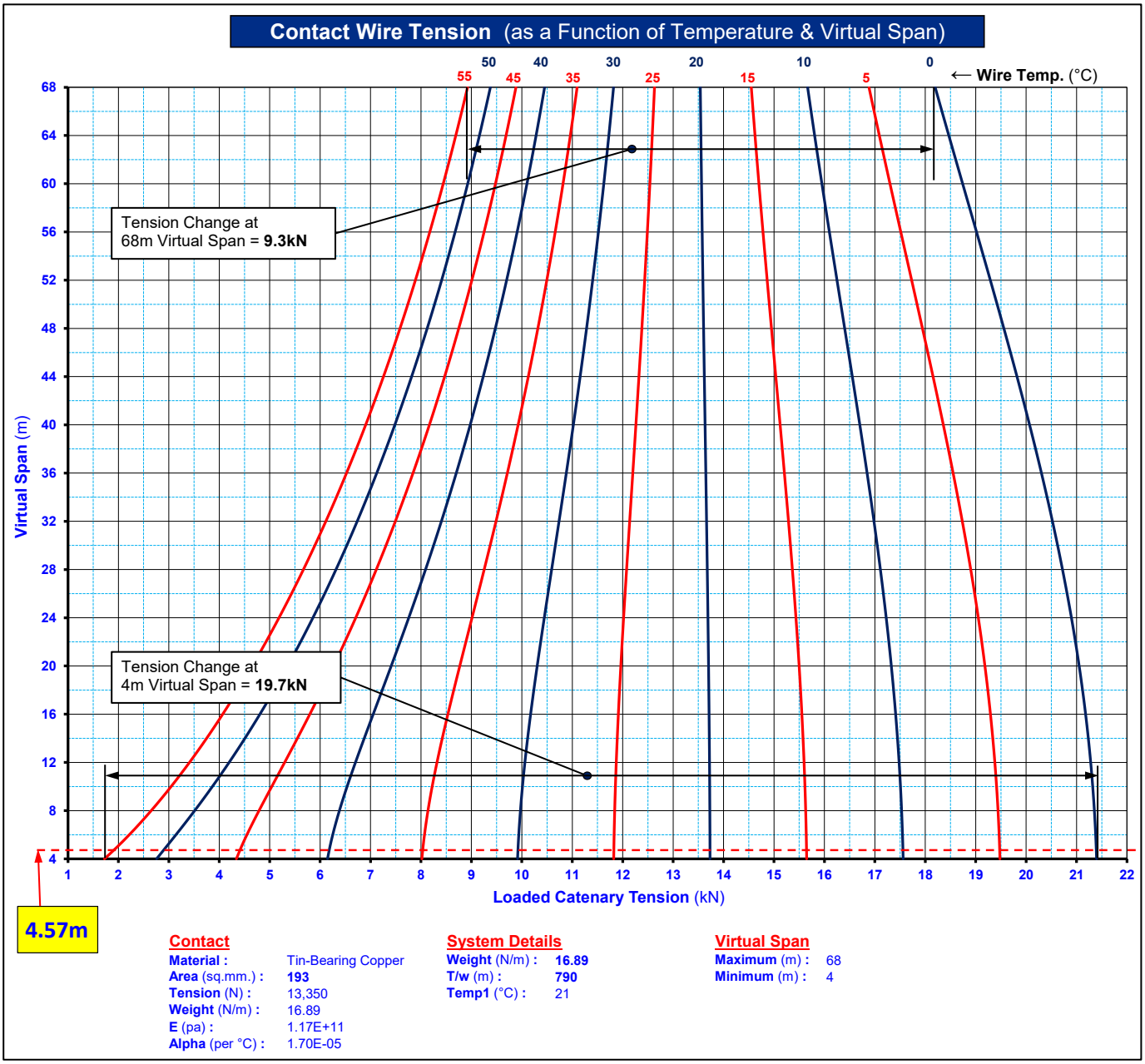

Contact Wire Tension (as a Function of Temperature & Virtual Span)
← Wire Temp. (°C)
55 50 45 40 35 30 25 20 15 10 5 0
Virtual Span (m)
68 64 60 56 52 48 44 40 36 32 28 24 20 16 12 8 4
Tension Change at 68m Virtual Span = 9.3kN
Tension Change at 4m Virtual Span = 19.7kN
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22
Loaded Catenary Tension (kN)
4.57m
Contact
Material : Tin-Bearing Copper
Area (sq.mm.) : 193
Tension (N) : 13,350
Weight (N/m) : 16.89
E (pa) : 1.17E+11
Alpha (per °C) : 1.70E-05
System Details
Weight (N/m) : 16.89
T/w (m) : 790
Temp1 (°C) : 21
Virtual Span
Maximum (m) : 68
Minimum (m) : 4

Figure 56 - (Equivalent) 193mm² Contact Temperature / Tension Chart

However, if a conductor does not sag much (i.e. in a short bay length), then the added length of wire due to heat may not be able to be taken up as additional sag, and so the tension in the conductor changes to a greater extent.

The extreme case of this is if the tensioned conductor is all resting on the ground and cannot sag at all. The extra length when it's hot goes directly into reducing its tension.

So, the ability of a wire to provide plenty of sag helps to minimise changes in tension due to temperature. The deeper the sag, the less tension variation happens with temperature changes.

The bay length for the catenary wire is typically between 30m and 70m. This can result in reasonably large sags (of the order of 400mm for 30m bay and 1,800mm for 70m bay).

The equivalent "bay length" for the contact wire is actually the distance between droppers, and this is typically only about 4.5m. Such a short distance cannot deliver much sag in the contact wire (typically only 5 to 10mm), so in contrast with the catenary wire, most of the contact wire lengthening with a higher temperature, goes directly into reducing its tension, which is not a good outcome.

Of course, the converse happens when the conductor gets cold.

Refer to Sydney Trains document GL E 73002, "Understanding Virtual Span" for a more detailed description of virtual span and its effects on OHW.

CONTACT WIRE "HOG" & "PRESAG"

To ***hog*** a contact wire is to raise the contact height towards the middle of the bay.

To ***presag*** a contact wire means to lower the contact wire toward midbay by an amount. (It is sometimes referred to as *bellying*). It's the opposite effect to *hog*.

Refer to *Figure 57* for what constitutes:

(a) *Contact hog*, and

(b) *Contact presag*.

Successive dropper lengths (between the first and last droppers in a bay) are designed to give the correct flat or near-flat (*hog* or *presag*) contact profile throughout each bay at the design tension.

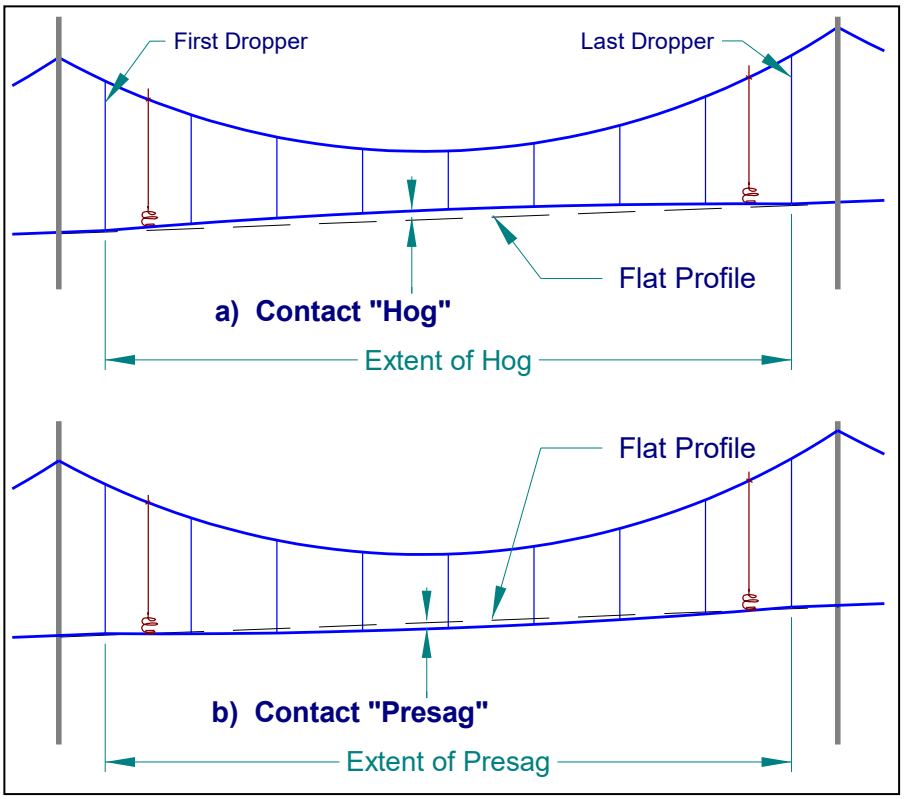


Figure 57 - Contact Hog and Presag

Hog

Contact hog is usually unwanted, but it happens in a fixed-anchored OHW system at cold temperatures. The hog shape leads to worse pantograph performance, especially at higher speeds (possibly causing arcing at the pull-off arms). → *Figure 57 (a)*.

Sometimes a hog can be deliberately introduced in a bay where the contact wire is already low and the track reaches the peak of a rise.

A good example of this happened in the Airport Line, which already had a low design contact height of 4.75m, and its track vertical profile in parts was like a roller coaster. If hog wasn't introduced, any individual bay spanning the track peak would result in a reduced contact height at mid-bay. So, hogging the contact wire could help compensate for this to deliver a suitable (higher) contact height at mid-bay, i.e. getting closer to 4.75m in the above example.

Presag

Contact Presag is often applied to all in-running bays of regulated OHW to help promote better OHW/pantograph interface at higher speeds. → *Figure 57 (b)*.

For Sydney's system, applying presag means that the contact height at mid-bay is lower than at the support by an amount given by "*L/1000*" (referred to as "L on a thousand"), i.e.

$$Presag = Bay\ Length / 1{,}000$$

So, for a 67m bay, instead of a perfectly flat wire, there would be 67mm presag (bellying) of the contact wire at mid-bay, which itself takes on an extremely shallow parabolic shape.

In a bay with a perfectly flat contact wire shape, a pantograph travelling slowly through the bay lifts the contact wire more at mid-bay. This is because the catenary wire becomes momentarily unloaded and it rises as the pantograph now supports the weight of the contact wire in that area. In response to this, towards and at midbay, the contact height (with pantograph under it) would be higher than at the supports.

To counteract this contact rise effect towards mid-bay, the purpose of presag is to make the uplifting pantograph work harder as it approaches mid-bay. This is done by slightly lowering the contact height as it heads to mid-bay, i.e. applying presag (through droppering). So, when the catenary becomes unloaded, the overall trajectory of the pantograph can be closer to being flat (a more constant contact height) throughout each bay, which leads to a more dynamically stable pantograph interface situation.

Introducing *presag* aims to minimise the disturbance (up & down oscillations) to the OHW run, especially to the contact wire. All subsequent pantographs of the same train have to cope with this disturbance as they pass through. Note that any disturbance is made worse in a compounding way by each successive pantograph of the same train, so the last pantograph can really bear the brunt. This is most noticeable at higher train speeds, and would likely lead to excessive pantograph arcing and even momentary loss of supply to that part of the train.

CONTACT UPLIFT WITH PANTOGRAPHS

Each pantograph on a train needs to have sufficient *upwards force* when sliding along the underside of the contact wire, so that it can transfer the heavy current that powers the train without causing arcing (seen as bright flashes between the carbon strips of the pantograph and the underside of copper contact wire). Any arcing will, over time, eventually damage something in this crucial interface area. (Note that arcing temperatures can be higher than those on the surface of the sun!)

In general, the higher the pantograph upward force, the better the electrical connection to the contact wire (with lower electrical resistance), and also the less chance of arcing (to a degree) as the pantograph traces this wire. This uninterrupted supply to the train is highly desirable.

The upward pantograph force for Sydney's electric trains is about 130N.

To counteract this large uplift force, there needs to be sufficient effective weight in the contact wire/s, otherwise the pantograph can rise to such a height that it can then clash with things it's not meant to hit, including other OHW conductor fittings (such as cross-spans, pull-off arms, etc.), station awnings, bridge fittings, tunnel linings, and anything else in its (now much raised) path. Having a large amount of uplift is also extremely bad for high speed running.

A few simple ways to counteract this upward pantograph force include:

- To *increase the weight of the contact wire*. This action was taken in the past when a heavier 193mm² contact size was introduced (probably in the 1960s?), which added a second standard (optional) size to the single smaller standard wire size of 137mm².
- To *double the effective contact weight by adding a second contact wire*. Twin contact OHW systems are popular for this reason (and for many other reasons).
- To *increase the contact wire tension*. This results in less uplift, as described in the under the next heading, and shown in *Figure 58*. This is one of the main reasons why regulated wire is preferred, since fixed-anchored wire loses its tension under hot conditions. Indeed, the contact tension can plummet to a mere 13% of its design (21°C) value! See *Table 17* below for an idea of its extremely poor tension performance at hot temperatures. Lower tension leads to a higher uplift figure, leading to a greater contact wire disturbance. Refer to the lower diagram of *Figure 59* a bit further on.

Simple Static Analysis

A stationary pantograph with typical upward force of 130N, will support (be counterbalanced by) a length of almost 8m of 193mm² contact wire weight. That's 4m of contact wire on each side of the pantograph. Refer to *Figure 58*.

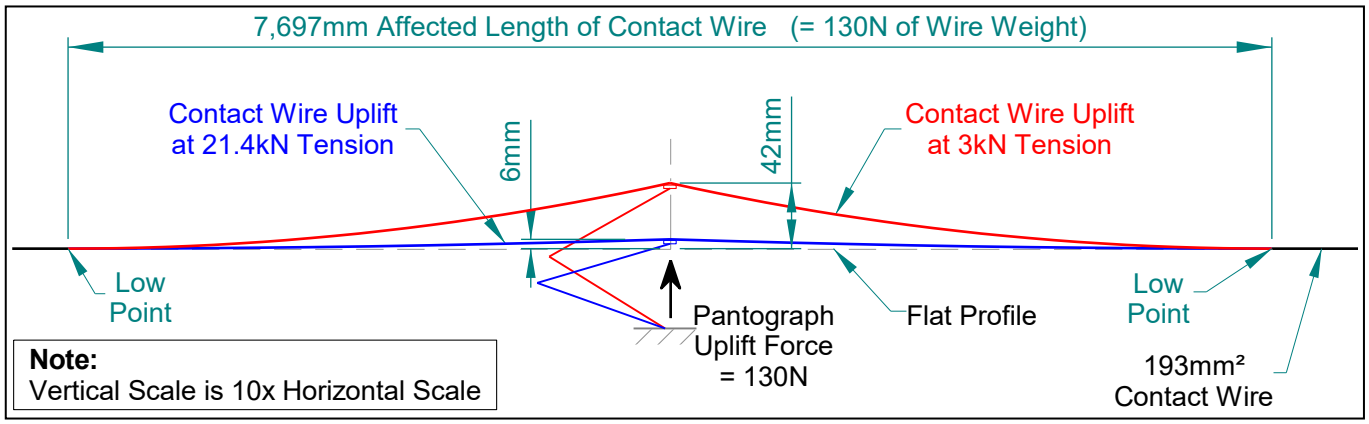


Figure 58 - Static Contact Uplift as a function of Contact Tension only

There are at least 2 aspects to consider here that affect static contact uplift:

Contact Wire. With a pantograph located under it, a length of fixed-anchored contact wire will rise by itself a mere 6mm at 21.4kN & 0°C, or a much larger 42mm at 3kN tension & 50°C (the cold tension is from *Table 17* a few pages back, and the hot tension is limited to 3kN, as described further below in the subheading *Contact Wire Stiffness*).
This shows the big impact that contact tension can have on the contact wire uplift component caused by its tension (or lack thereof).
It also demonstrates why increasing the contact tension to a high value (18kN) AND regulating it can both bring about big benefits to help minimise static (and dynamic) pantograph uplift. 18kN lifts the 193mm² contact wire by only 7mm.

Catenary Wire. The profile of the contact wire is set by the catenary shape and the distributed positions and lengths of the many supporting droppers in a bay. A pantograph located under a 193mm² contact wire supports almost 8m of its length, so the weight of this does not need to be supported by the catenary wire above. Therefore the lighter load on that portion of catenary wire causes it to rise a bit. This tends to drag the contact wire up as well. This effect is most pronounced at mid-bay (maximum catenary sag).
Tightening the catenary tension reduces the amount of such rise, which is good.
Note that any large contact uplifts that cannot be accommodated by the catenary rising as much, will result in the supporting droppers in that area becoming momentarily loose until the pantograph passes.

Note:

> The above calculation of contact rise assumes that the contact wire is infinitely flexible. But it's not – this single-stranded solid wire is rather rigid like a straight bar, so the actual values of rise will not be as great as those calculated, which is good. But the idea is there.

The above catenary & contact effects are compounding, and they combine to produce a rather complicated situation to assess. When you add train speed and multiple pantographs to the mix, (as well as pantograph aerodynamics, etc.), it's no wonder that it requires sophisticated computer programs to predict the behaviour of the pantograph/OHW interface at speed.

However, put simply, if a train is travelling fast, this pantograph uplift effect becomes complicated, and it can lead to significant OHW disturbance, particularly towards mid-bay. The wires have mass, and the resulting generated wire oscillations have momentum. So, these oscillations can propagate to some degree into adjacent bays and throughout the wire run,

which other trailing pantographs of the same train then need to negotiate.

Note that the damping mechanisms on modern pantographs help to reduce both the uplift disturbance and also any OHW oscillations that might be generated.

Pantograph Spacing

The spacing between successive pantographs on a train can cause problems too.

To give an idea of the close pantograph spacing, when locomotives used to traverse the electrified network, a double-header 46 Class locomotive could have 4 pantographs pushing up against the contact wire. There was about 9m spacing between pantographs on a locomotive and 7.5m between the last pantograph on the leading loco and the first pantograph on the following loco. And there were often triple and quadruple header locomotives in operation (up to 8 pantographs) – that's a huge localised upward force, which greatly exacerbated the pantograph uplift & OHW disturbance problems.

The excessive contact wire uplift has been such an issue that restrictions were needed to be enforced on certain lines throughout the network, which limited the number and spacing of pantographs on multiple-header locomotives, especially under hot conditions (particularly hot days in Summer). For example, one limit was to only allow 1 pantograph (not 2) per locomotive, in certain vulnerable regions of the network on those hot days.

Note that the heavy current drawn from a fully laden (and therefore slow) locomotive is enough to progressively heat the contact wire to high temperatures, and so, even on cool days, contact uplift may have been a problem in certain parts of the network.

This is no longer a problem in Sydney's system – electric locomotives don't operate any more (I'm reasonably sure it's not for this reason alone). But this history gives a bit of an idea of why there was a contact uplift problem, and of some of the solutions (amongst others) that were put in place in the OHW system.

CONTACT WIRE STIFFNESS

Standard EP-08000017-SP, "OHW Conductor System Selection", talks about the contact wire "stiffness", and that, for an acceptable interface with a train's pantograph, the product of the contact weight when new (in Newtons per metre) and its minimum tension (in Newtons) should be greater than 50,000 (N^2/m).

For the 2 contact wire sizes, this means that the hot temperature in the contact wires needs to be limited in order to give the necessary *minimum tension* of:

- 3kN for 193mm²,
- 4.2kN for 137mm² and
- 2.1kN each for a 2x137mm² twin contact system.

So, obviously none of these conductors can afford to get as hot as 55°C (per the above table), and more likely their maximum operating temperature should be no more than about 50°C.

For example, refer to *Table 8* (further back), which shows OHW current ratings for various major OHW systems, and gives an idea of what actually limits the current rating (items are double-asterisked – **). The last entry in this table shows System 21, a fixed-anchored 270mm² catenary / 193mm² contact system, which is ultimately limited by the contact wire temperature (49°C). This is no doubt because the slack tension, at this temperature, causes its stiffness to go lower than the above 50,000 figure. As the wire wears, both its weight and its tension reduce, making the stiffness figure much less which is no good, but the system current rating should be reduced anyway due to the reduced copper CSA in the air (with worn contact wire).

CONTACT WIRE DYNAMICS

Any oscillations generated in the contact wire can take a while to settle down, due to the mass (inertia) in the wire. If oscillations are set up by the first pantograph at speed, then this first pantograph passing through each bay may be OK, but the following pantographs of the same train will experience more physical disruption in a compounding fashion as each subsequent pantograph passes, with the last one bearing the brunt of activity. It may actually lead to significant arcing and power interruption to the train.

These days the pantographs include dampeners to effectively reduce or limit the amount of contact wire disturbance, which is a good outcome.

By world standards, Sydney doesn't have high speed trains.

Overseas trains operating at very high speeds of 300km/h and above require a much higher operating voltage – usually 25kVac.

Importantly, for them to operate at these speeds, they can only afford to have 1 pantograph in touch with the contact wire, and this single pantograph needs to supply power to the entire train. This is because the disturbance to the contact wire of this 1 raised pantograph, travelling at such high speed, is far too much for any following pantograph/s to cope with (pass through).

Even so, I understand that very high speed operation requires that the OHW characteristics be carefully designed to ensure that the "critical speed" (wave propagation velocity) of the OHW is always higher than the maximum train speed. This generally means increasing conductor tensions to the maximum.

It seems if the critical speed is reached, an uplifted pantograph generates its own wave in the contact wire that travels ahead of the train, and which it then needs to pass through (with possible dire consequences).

At this stage, Sydney doesn't need to be concerned with critical speed, as the trains and electrical supply (and probably track and signalling) are only suitable to about half the above speeds. However, the standard OHW system (System 2) is suitable for speeds to about 160km/h (per standard EP-08000016-SP), and I understand this system was checked out for its critical speed before its initial inception in the late 1980s.

Fixed-Anchored OHW

Figure 59 is intended to indicate how the *low contact tension* at hot temperatures in a fixed-anchored OHW system produces a contact profile that's quite unsuitable for higher train speeds.

The upper diagram shows the amount of sag between droppers (contact *ripple*) that the pantograph head needs to trace through at speed. This ripple can be up to about 30mm at 55°C, as indicated further back in *Figure 24*. While 30mm doesn't seem much over the 5m distance or so between droppers, at higher train speeds this can possibly become a problem for the pantograph.

The lower diagram in this figure gives an idea of the static shape of the contact wire when hot, and the way the pantograph can really influence the contact wire height as it pushes up against this wire throughout the bay, and unloading the contact wire from the catenary supporting it in the process. And this can generate quite large wire oscillations that continue for a while due to the momentum it sets up in the wire. And of course, the subsequent pantographs then have to pass through that disturbed wire.

Obviously, regulated OHW is far superior in these circumstances of higher train speeds.

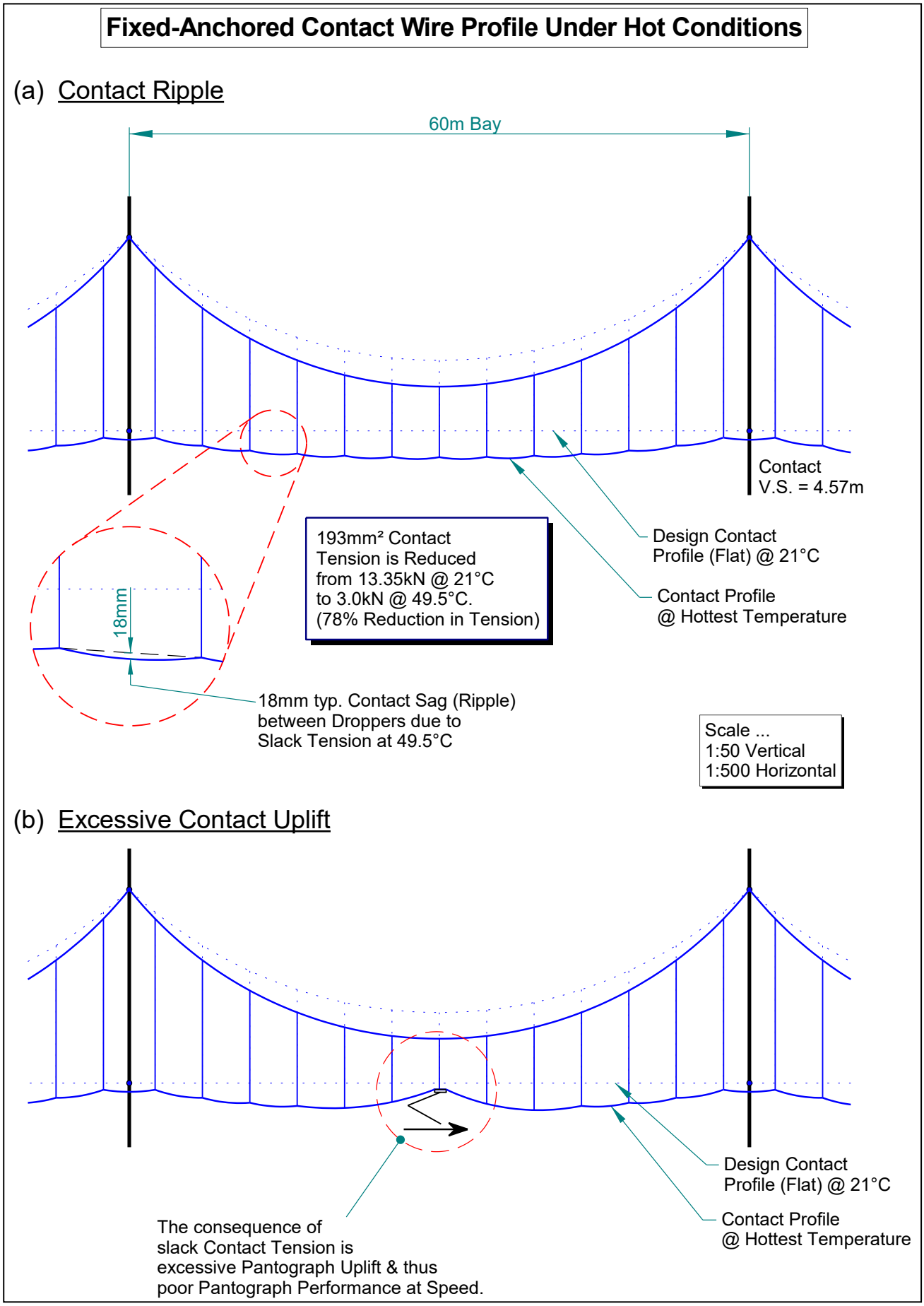


Figure 59 - Fixed-Anchored Contact Uplift when hot

CONTACT STAGGER

Stagger Definition

Contact wire *stagger* is the horizontal offset of the registered contact wire relative to the superelevated track centreline at contact wire height – see *Figure 60*. It's the sideways positioning of the contact wire with respect to the design centre of a train's pantograph.

The contact wire is staggered at its registration point with a *pull-off arm*. This will almost always change the direction of the contact wire at that point (which results in radial load in the arm), and it gives the wire a certain alignment in both adjacent bays. See *Figure 61*.

These days, on ***straight track*** (infinite track radius), the standard contact stagger at support & registration locations alternates **±250mm** – see *Figure 61 (a)*.

On ***lightly curved track*** (down to about 2,000m track radius), a stagger **less than 250mm** can be used.

On ***curved track*** (tighter than 2,000m track radius), the standard stagger at each end of the bay is:
+250mm (down to 800m track radius), and
+300mm (below 800m track radius) – see *Figure 61 (b)*.
These staggers are towards the outside of the track curve.

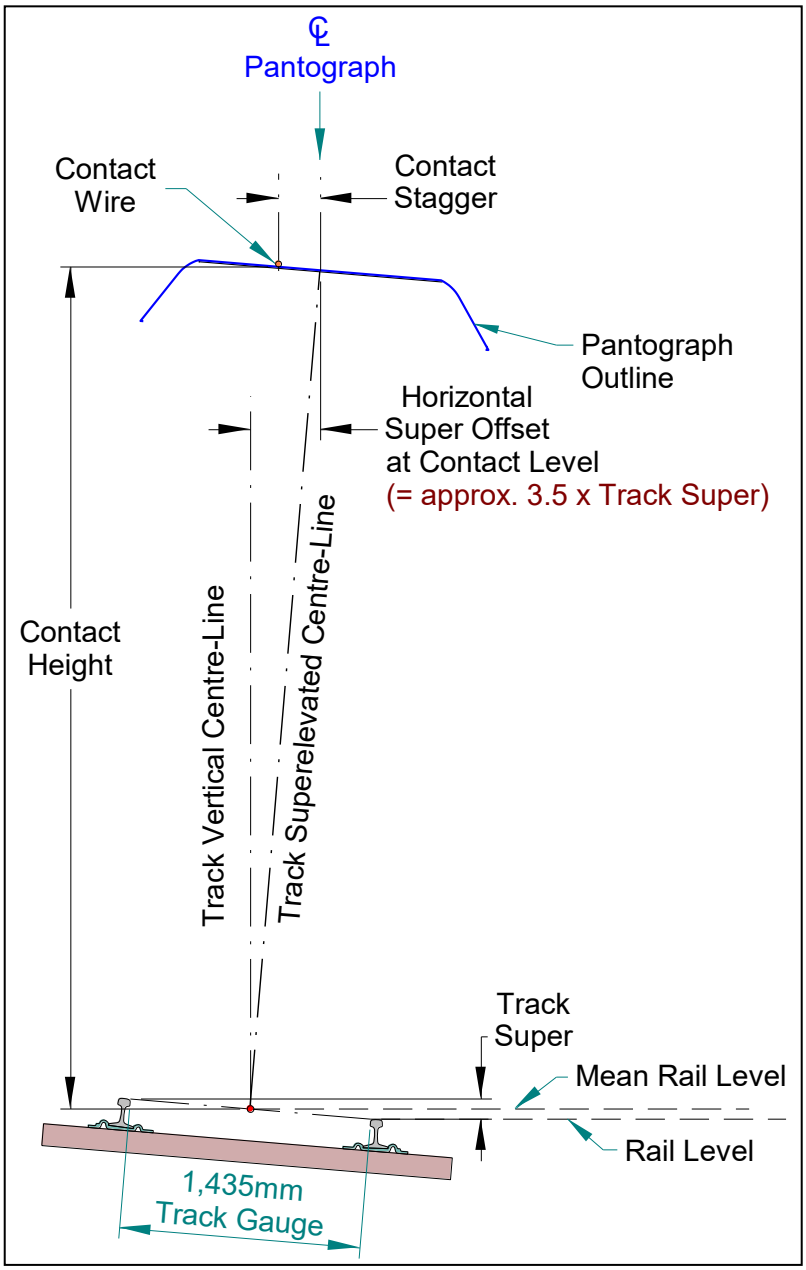


Figure 60 - Contact Stagger relative to Track

Note that I have added a diagram below *Figure 61 (b)* which shows the same situation but with an unmagnified scale. It was added to help demonstrate how a magnified lateral scale is necessary in order to better comprehend the actual situation with staggering. The workings using an undistorted scale makes it very difficult to understand.

The standard staggering policy and details are given in the relevant "Structure Spacing Chart" for that OHW system – see *Figure 169* further on for an example (based on signed drawing EL0009386).

The larger 300mm stagger figure was introduced in the 1980s to help improve pantograph security on tight curves. And it also helped spread the wear on pantograph carbon strips (in an attempt to make them last longer before needing to be renewed).

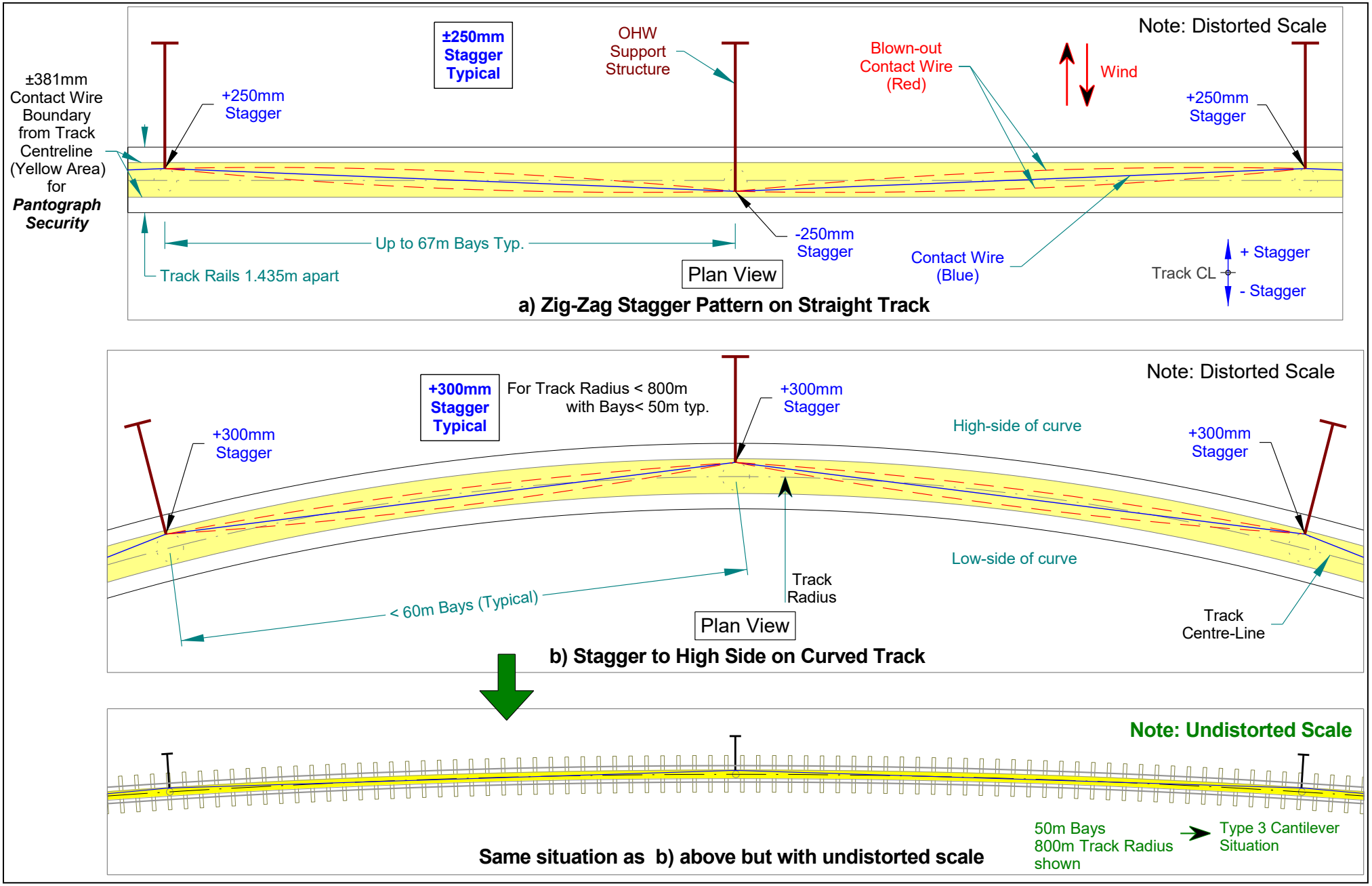


Figure 61 - Staggered Contact wire patterns for straight & curved Tracks

Stagger with Twin Contacts

In the case of *Twin Contacts*, the stagger is referenced to the *mean* (or *average*) contact position, which is midway between the 2 contact wires. Unfortunately, measuring to this midway position can make accurate stagger measurement in the field difficult.

This situation is shown in *Figure 62*:

- With standard 150mm twin contact separation, individual wires are staggered ±75mm from design value, i.e 175mm and 325mm.
- With 50mm twin contact separation, they are individually staggered ±25mm different from the stagger value, i.e. 225mm and 275mm.

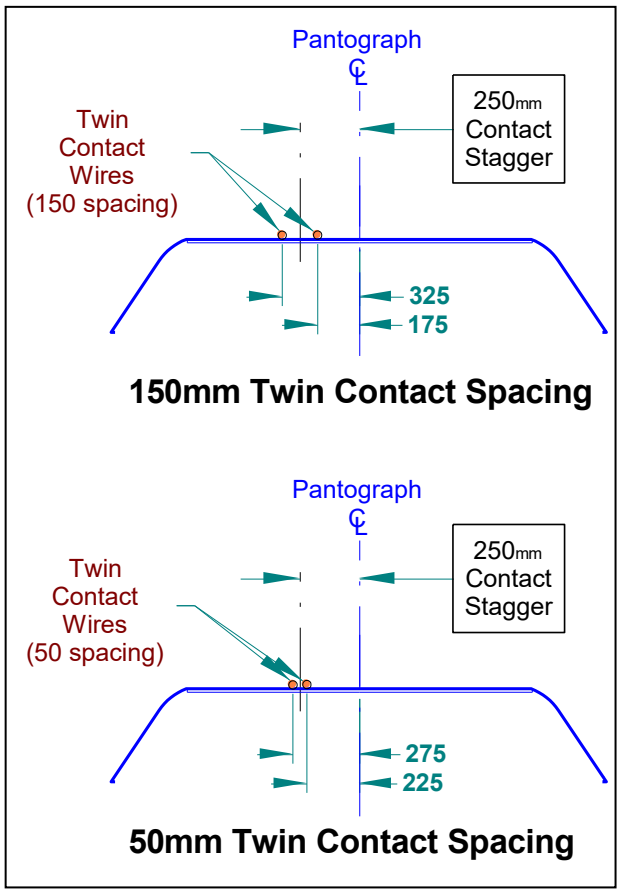


Figure 62 - Twin Contact Stagger

Stagger Outcomes

Contact stagger achieves 2 main things:

- On ***straight (tangent) track***, having opposite staggers at each end of the bay, as shown in *Figure 61, Case (a)*, causes the contact wire to sweep left or right across the moving pantograph – to *zig-zag*. This reduces localised wear on the pantograph's carbon strips, and hopefully extends the life of the carbon strips. The staggers are typically +250mm towards one side of track at one end, to -250mm at other end, as depicted in this figure.
- On ***curved track***, staggering to the *high* side of the track, as shown in *Figure 61, Case (b)*, also aims to sweep the contact wire across the pantograph, but more importantly it enables *longer bay lengths* to be achieved on these curved tracks. This in turn reduces the number of OHW supports needed per kilometre (and their consequent construction and ongoing maintenance costs). A wire staggered to the high side of the curve at each end of the bay quickly heads towards the low side of the curve towards mid-bay. Refer also to *Figure 65*. For regulated OHW, the staggers around curves are typically 250mm to the high side on shallow curves (from non-tangent track such as 2,000m, down to about 800m radius) and increased to 300mm on tighter (smaller radius) curves as shown in *Figure 61, Case (b)*. It would likely be a similar situation for fixed-anchored OHW.

In Case *(a)*, a contact wire with no stagger at all on straight track (zero stagger) will tend to wear a groove in the centre of the pantograph carbon strips. Such a localised wear pattern is highly undesirable, as any such groove will cause poor contact wire tracking when it's forced to sweep across the carbon strip around track curves. And, if not identified and corrected, such localised wear will lead to premature failure of the pantograph and/or OHW (i.e. contact wire could eventually rub against the steel of the pantograph carbon strip holders). So, the life of the carbon strip would be significantly reduced, and pantograph / contact wire performance would probably also be quickly rendered ineffective (with much arcing).

Figure 63 shows a highly worn area towards the centre of the pantograph (almost to the level of the stainless steel carrier that the carbon strips are retained by).

This dish-shaped wear is typical of the progressive wear pattern on the carbon strips, because for much of the time, the contact wire is close to the centre of pantograph, even though it might be staggered at 250mm or 300mm at most S&R locations.

Figure 63 - Typical Pantograph Carbon Strip with localised wear near centre

In an ideal world, the contact wire would sweep across all the width of carbon strips in each bay of OHW, so as to extend the life of the strips and promote a more uniform wear pattern. But … only half the pantograph width is available, due to the additional width needed to cater for other *tolerances* (track, vehicle sway, etc.) – see *Figure 67* and below subsection on *Pantograph Security*.

Figure 64 shows a somewhat aerial view of the OHW conductors which are staggered in a zig-zag fashion on straight track in the foreground, and staggered to the left to go around the right-hand curved track in the background (if you strain your eyes).

Note that the large degree of carbon strip wear towards the centre of pantograph, seems to be a common complaint from the mechanical section in charge of their maintenance. Their hope is that the OHW staggers could somehow be increased (or otherwise improved) to help spread the uneven wear to other unworn areas of the pantograph. However, the "pantograph security" requirement for contact wires to be within ±381mm from centre of pantograph, limits what can actually be improved.

The extra width of the pantograph is there to accommodate the tolerances of the 3 interfacing systems, as explained in the subsection *Pantograph Security* further on. It is also used when an adjacent contact wire is taken up from the horn onto the top of pantograph, in crossover and turnout situations.

However, having twin contacts can help spread the wear to a degree, because the outside wire can be about 75mm further out along the carbon strips.

Figure 64 - Staggered wires on straight Track

Contact Wire Offset

The contact wire *Offset* is the horizontal distance from the contact wire to the superelevated centreline of track, at any location within the bay.

Changing the staggers at each end of the bay will alter these offsets throughout that bay.

Mid-Bay Offset

Of significant importance is the *Mid-Bay Offset* (MBO) which, as its name states, is the contact lateral offset from the superelevated track measured at mid-bay.

A contact wire staggered at each end of the bay will have a mid-bay offset that's a function of both *end staggers*, and of the *track versine* between these points. Here, "Versine" is the horizontal offset of the track at mid-bay relative to a straight-line chord strung between track centres at both ends of the bay. See *Figure 65*. On a constant curved track,

Versine = (Bay Length)^2 / 8 / Track Radius.

On *curved track*, the staggers at each end are normally to the *high side* of the track, as this is in the direction to counteract the effect of track versine. This results in the mid-bay offset being closer to zero, i.e. the contact wire is closer to the centre of the pantograph when at or near mid-bay. The maximum blowout is then added to, or subtracted from, the staggered wire at this location – refer to "**Blowout (+)**" and "**Blowout (-)**" in *Figure 65*. Refer to subsection *Contact Blowout* further below for more on blowout.

Note that if the staggers are identical at both ends of the bay (e.g. both are +300mm), and the track is a constant radius curve throughout the bay, only then will the maximum blowout occur at exactly mid-bay (see next Section).

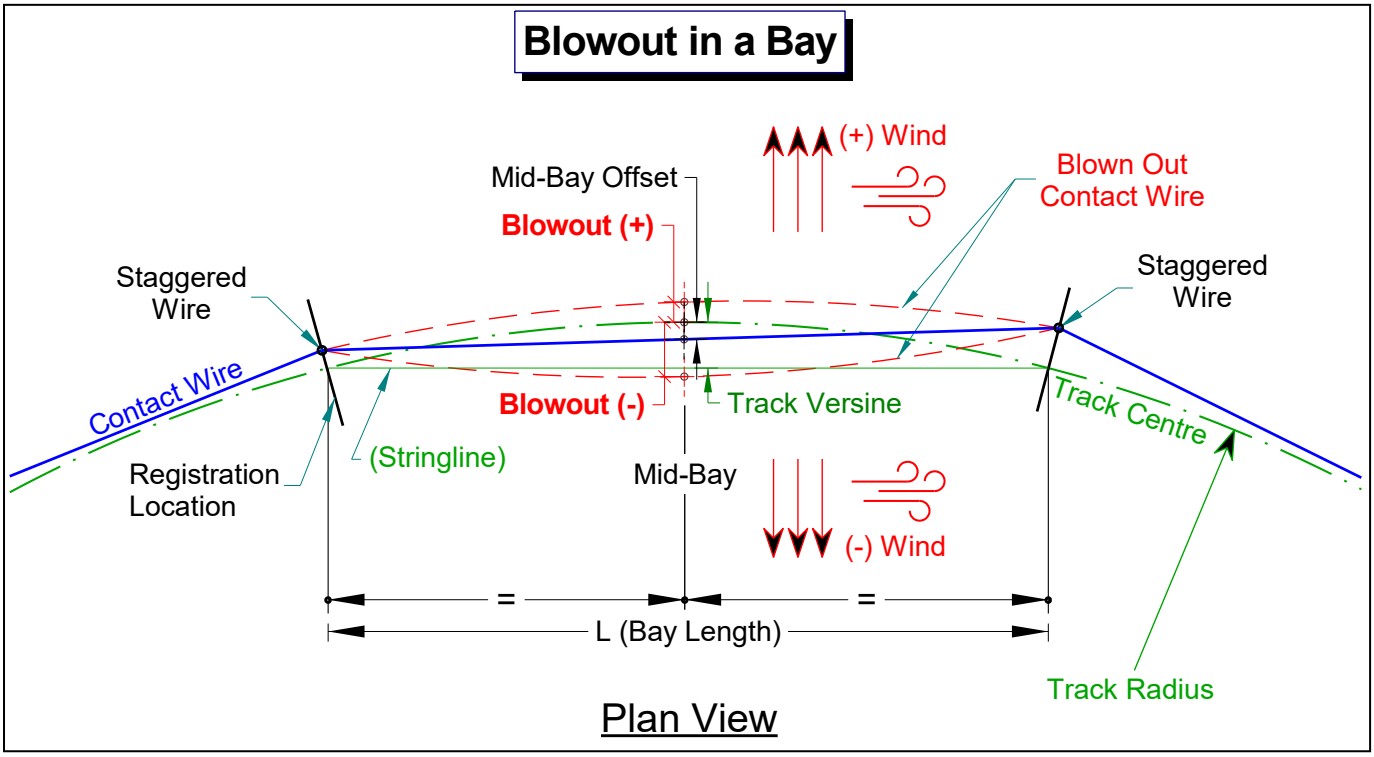


Figure 65 - Contact Blowout in a Bay

As mentioned previously, the big benefit of this staggering is that the bay lengths can be longer than they would otherwise be, which is a good outcome (yielding less OHW structures needed per kilometre). It also helps promote more even pantograph wear, since the wire sweeps further across the carbon strips from one side to the other as the pantograph passes through the bay.

It's also important because the mid-bay location has the least control over the contact wire placement relative to track, i.e. it is as far away as possible from the staggered positions registered at each end of the bay, which have relatively solid positions that are effectively controlled by the pull-off arms.

So, quite often the contact offset is measured midway to help confirm pantograph security.

See *Figure 66* for an example of staggering around a curved track.

For more information on the reason for stagger, refer to *Pantograph Security* further below.

Figure 66 - View showing Staggered Conductors around curved Track

Transitioning Track

One of the complications with pantograph security happens where the track changes from one horizontal radius to another, e.g. from 800m radius to tangent track (infinite radius).

On main lines, there is usually an intermediate length of track that will gently "transition" from the one radius to the other. (On slow speed lines such as sidings, there is less need for any such transition.)

The geometry for such a *transition* involves a mathematical *cubic parabola*, which is a bit like a spiral, but apparently it's easier to set out the geometry in the field with this method.

Fortunately, the change of superelevation through the transition is *linear* – nice and simple. So, in the above example, a track radius of 800m may have 100mm of track superelevation, and tangent track has zero superelevation, so half way through the transition the superelevation would be 50mm.

The transition is needed to help the trains to negotiate the altered track geometry, and it particularly helps with passenger comfort. (With no transition, there would be a sudden sideways jerk at that track geometry change point, which is no good for the track, or the train, or the unfortunate people travelling inside the train!)

In terms of the design of overhead wiring through a transition, this can be quite difficult to stagger and have confidence that pantograph security is assured. The complex track geometry in the transition area is further complicated by the corresponding linear change in track superelevation. This can lead to problems unless a cautious approach is adopted in its design!

There was a computer program written in the 1980s that accurately modelled this complex track alignment situation, and generated some optimised OHW alignment (staggers) necessary to ensure pantograph security. In particular, this allowed the bay lengths to be maximised in this area (thus cutting down on initial construction and on-going maintenance costs).

The computer program apparently worked well. But it required the operator to have a good understanding of what was actually being modelled.

Sadly, there was one incident that resulted during the Waterfall to Pt Kembla Electrification Project in the mid-1980s, where the program was used to analyse a particularly complex situation of reversing curves with transitions (as I recall). Apparently, a design mistake was made using this program (due to a misunderstanding), and when the OHW was built, it resulted in the loss of pantograph security through the transition/s – the bay lengths were likely too long. It led to damaged pantographs on one train and brought down the OHW, which stopped trains for quite a while.

This lack of understanding of the workings of this "transition" program, subsequently led to the policy of simply keeping the same shorter structure spacing (based on the track curvature) throughout the transition area (which sadly meant abandoning the program).

While this approach might result in one additional support & registration location, it was seen as a way of minimising the risk of a similar problem occurring in the future. This policy has worked well ever since, and is in the Electrification Standard.

CONTACT BLOWOUT

High wind speeds acting against the side of a tensioned contact wire cause it to deflect sideways or *blowout* from its static straight-line position, and the greatest lateral movement from this alignment occurs at mid-bay.

In most situations, the amount of catenary wire blowout is quite similar to that of the contact wire. However, the contact wire has to perform the more vital role of directly supplying current to the train's pantographs, whilst also controlling the pantograph's height.

It is thus imperative that the position of the contact wire be maintained within certain limits on the pantograph, even under high wind situations. This is an important task for the OHW designer, and is one of the principal elements in ensuring *pantograph security* (see below).

Blowout Value

The amount of blowout on a conductor depends basically on its shape (including diameter and surface "roughness"), its tension, the wind speed and the bay length, as seen in *Equation 3* below for the contact wire (and quite similar for catenary wire).
Note that the round sectional shape of the contact and catenary wires is probably the most ideal shape for minimizing the amount of blowout, which is a good thing.

$$BO = \frac{0.0046\ d\ V^2\ L^2\ k}{T}$$

Equation 3 - Contact Blowout

Where,

BO = Blowout (m)
d = Diameter of Contact Wire (m)
V = Velocity of Wind (km/h)
L = Length Between Pull-off Arms in a Bay (m)
T = Tension in Contact Wire (N)
k = Shielding Factor

Note:

In the case of twin contacts, the second contact wire is partially shielded from wind by the first contact wire, and the blowout on the second wire is thus less. Blowout for the second wire is typically reduced to roughly 90% of that of the first wire which experiences the full wind. The value of *shielding factor* "k" in the above equation takes this into account.

Example:

A 193mm² contact wire has a diameter of 16.4mm and is installed at a tension of 18kN. What is the contact blowout in a 67m bay with 130km/h wind speed?

Solution:

$$BO = \frac{0.0046 \times 0.0164 \times 130^2 \times 67^2 \times 1.0}{18{,}000} = 0.318\text{m}$$

Blowout is a function of (Bay Length)², so if you halve the bay length, the blowout is reduced to one-quarter of the value. Conversely, if you double the bay, it gives 4 times the blowout.

Now, if a bay includes 1 (or more) intermediate pull-off locations, then the maximum blowout between successive pull-off arms is much reduced (because "L" is reduced). So, in the above example, if a pull-off was installed at mid-bay, then the 2 separate shorter spans would exhibit a blowout of ¼ of 318mm = 80mm (only). Obviously, installing a mid-bay pull-off can dramatically improve pantograph security in certain circumstances.

The dashed red lines back in *Figure 61* and in *Figure 65* both show the blown-out contact wire with wind blowing in the 2 opposing directions perpendicular to the static contact wire position (in blue).

Wind Speed

Typical maximum wind speeds for determining the maximum contact wire blowouts are:

a) For *regulated* OHW: 130km/h.

b) For *fixed-anchored* OHW: 130km/h @ 0°C ***or*** 80km/h @ 40°C, whichever gives the greatest blowout amount, although it's usually the latter condition that rules. (Note that this used to be 80miles/h & 32°F and 50miles/h & 100°F respectively.)

Blowout Tension

For regulated OHW, the design value of contact tension is used in the blowout equation.

However, for fixed-anchored contact wire, a Temperature/Tension calculation is needed to determine its worst-case blowout tension value, and this is usually at the 80km/h @ 40°C value. For example, a 193mm² contact wire has a typical "blowout" tension at 40°C of about 6.2kN, with the details shown below in *Table 18*.

Contact Details …

Aspect	Value
Tension	Fixed
Design Tension (kN)	13.35
Design Temperature (°C)	21
Virtual Span (m)	4.57
Adverse Temperature (°C)	40
Adverse Wind Speed (kph)	80
=> Blowout Tension (kN)	**6.172**

Table 18 - Typical F/A Contact Blowout Tension

Maximum Blowout in a Bay

The design of OHW requires that the contact wire be no more than 381mm (15") from the superelevated centreline of track *anywhere* in the bay.

The wind can cause both the catenary and contact wires to experience blowout.

Quite often the static wire position (no wind blowing) at *mid-bay* is designed to be *at or close to zero*. By doing this, when the wind blows in the 2 directions perpendicular to the wire at the maximum speed designed for, it will result in equal or almost equal lateral excursions about the centre of pantograph at mid-bay. This somewhat ideal position helps assure pantograph security in that bay. But there is a slight complication to this approach.

As mentioned, on *straight track* (with no versine), the end staggers of +250mm towards one side of track at one end, to -250mm at other end, provides a "zig-zag" stagger pattern when viewed from above – see *Figure 61 (a)*. This is done to help provide more even wear and over a wider range on the pantograph carbon strips.

Unfortunately, these ±staggers also produce a greater blowout value in the bay, and the *maximum contact wire offset to the pantograph doesn't necessarily happen at mid-bay* – it's more likely to be located closer to one and/or the other registration locations.

So, this *Maximum Blowout* value needs to be calculated to be within its limits for pantograph security. Unfortunately, having zero staggers at each end of the bay produces the smallest blowout in the bay – but this will rapidly wear the carbon strips as discussed above!

If the *Structure Spacing Chart* (for the relevant OHW system) had been strictly adhered to when the structures were first set out, then there should be no need to calculate the maximum blowout in each bay (provided the nominated staggers were used).

Note:

> The "KF-ROW" computer program can readily work out the *location/s within the bay* which will have the maximum blowout, and what that *maximum blowout value* is. This needs to be less than the maximum 381mm (for single contact). If that can't be met, then changing the staggers may help, or maybe the bay length needs to be reduced – somehow.

PANTOGRAPH SECURITY

The whole point of the OHW system is to reliably supply electric power to trains, so it is most important that the train's pantographs remain in contact with, and controlled by, the contact wire – at all times.

There are 3 elements to this system – the *OHW*, the *track* and the *train*. Each of these elements have imperfections that require tolerances to be adopted in order to ensure that the train's pantographs always remain on the contact wire. This is even with the track moving small amounts vertically and laterally over time, with the vehicle swaying, and with wind blowing (at 130km/h), etc.

See *Figure 67* for the lateral space needed to ensure pantograph security throughout each bay of OHW.

The so-called imperfections are briefly summarised below.

a) The ***OHW***. The contact wire is rigidly restrained at each pull-off registration location (usually installed at both ends of each bay). However, the wire is free to move laterally as crosswinds blow. These days, the OHW is designed to maintain pantograph security with wind speeds up to 130km/h. The maximum wire displacement under the influence of wind occurs midway between adjacent pull-offs, and depending on the staggers at each end, this is usually the area most vulnerable to the loss of pantograph security due to the OHW.

b) The ***track***. It can move about in 3 dimensions over time – lateral, height and superelevation (but should always remain within its stipulated tolerances).

c) The ***train***. There can be various loose connections, including the bogie connection to the train chassis, pantograph pivot connections, etc.

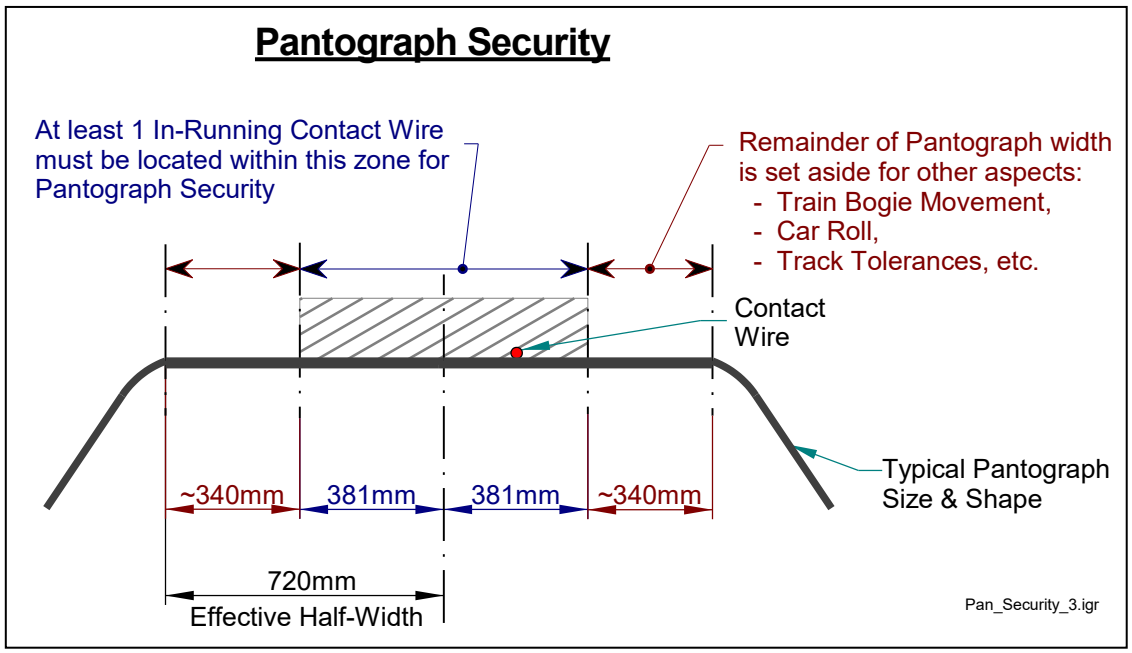


Figure 67 - Apportioning space for Pantograph Security

When designing new OHW, the maximum bay lengths that can be used for a particular wire system are obtained by referring to the appropriate "Structure Spacing Chart" for the relevant OHW system. This is covered in more detail in *Section 3.2*, but basically the bay lengths are limited by the track radius, and this chart gives all the details.

For more details on pantograph security refer to *Section 6.3.2.2*.

CONTACT HEIGHT

Contact height is the vertical height from *mean rail level* to the underside of the contact wire. The mean rail level is defined as the average height of the top inner-running faces of both rails of the track – at the track centre. It can also be thought of as the level of the lower of the 2 rails plus half the track superelevation. See *Figure 60* further back.

Although contact height can be measured anywhere within each bay, it is the support locations at each end of the bay that are the focal point for establishing the contact heights for that bay.

The contact height at each location is determined as part of the OHW design.

Mid-bay is another important location for measuring contact height, especially for any fixed-anchored OHW which tends to hog and belly from its flat (21°C) condition under cold and hot temperatures (respectively). It can be measured to ascertain that the contact wire is behaving as it was designed to do (provided the track cooperates too!), and particularly that it doesn't droop so much as to come anywhere near the top of a train. Unlike at the supports where the wire can be well controlled, at mid-bay the contact height is a function of the catenary sag at that point, and this is much less well controlled (it's influenced by all sorts of things, especially catenary tension).

It is necessary to adopt a uniform (standard) contact height at support locations wherever possible, mostly so that the train's pantographs are more likely to remain at a certain level and not move wildly up and down from bay to bay (at least in a regulated OHW system). This aims to minimise the wear on the various pivot points of the pantograph. More importantly however, this promotes good, stable current collection from the contact wire to the head of the pan, and minimises pantograph-to-contact wire arcing (which can otherwise lead to supply interruption to the train and progressive arc erosion wear at this interface point).

In the early days of Sydney's electrification, the adopted standard contact height was 5.03m from the British system at that time (16'-6" in imperial measurement).

These days the standard contact height is 5.0m.

For various reasons, the contact height at support locations can be altered between minimum and maximum values, and even these values can vary from area to area or project to project, depending on the specific circumstances.

For instance, in the past, when upgrading OHW, it was normally desirable to bump up the standard contact height from 5m to 5.2m in areas with timber sleepers, so when they were eventually replaced with the thicker concrete sleepers, the height would come down closer to the standard 5m value with little or no additional effort. One such project was the Gosford to Newcastle Electrification in 1980-84.

Minimum Contact Height

The ***minimum contact height*** is typically 4.75m, and this lower height is often needed when tracks pass under low overline bridges (OLBs) and inside tunnels, where vertical space is often restricted.

A ***lower minimum contact height*** of 4.65m can be used, subject to obtaining permission from standards (which requires that the need for this be demonstrated).

The ***absolute minimum contact height*** anywhere in a bay and under the worst conditions (e.g. for fixed-anchored OHW at the hottest temperature) is 4.57m, which is then only 150mm above the roof of a double-deck train. There are certain areas, notably the City Underground, where this height has needed to be reduced even further to 4.52m (only 100mm above the top of train), which is likely due to the decision to convert from single to double-deck trains in the 1960s.

Refer back to *Section 2.7* for other details.

The derivation of the 4.75m height figure was given in the Appendix in "OHW Standards for the Electrification of New Routes", EP-08000001-SP.

Maximum Contact Height

The *maximum contact height* is typically 5.8m.

These higher heights are normally required at public and private level crossings to cater for road vehicles passing under, and still have at least 1m vertical clearance to the contact wire (under the worst case) from any part of the vehicle. If only all vehicles would cooperate! Refer to Standard EP-08000012-SP, "Level Crossings – OHW Clearance Requirements". See also *Section 6.4.5*.

Low Contact Height

The fixed-anchored OHW system is a simple technology, and it's relatively easy to construct. It has served Sydney quite well since the first days of electrification, provided it was properly designed and built and maintained to ensure reliable running at the temperature extremes. In

particular, the hot weather used to cause problems, notably with the contact wire sagging close to the top of a train or even resting on it! Trains stop.

The most vulnerable areas were usually the approach to, and under, the (usually low) overline bridges. This is where the catenary wire had to be squeezed under but still remain electrically clear of the bridge above, while the supported contact wire had to be clear of all trains below.

With an already low contact height in these areas, it doesn't take much heat to cause the fixed-anchored catenary wire to lower at mid-bay, causing the supported contact wire to lower in sympathy, to result in a *Low Contact Height* problem.

A number of approaches had been used in the past to try to control this situation, in what was Sydney's vast fixed-anchored network. They met with varying degrees of success. Fortunately, the extent of this type of wiring has vastly diminished over the past 50 years since regulated OHW first appeared. Even so, there still remain pockets here and there of fixed-anchored OHW that are exposed to the elements and with portions that pass under bridges. (Note that fixed-anchored OHW inside tunnels generally does not pose the same problem – there are no bridges inside tunnels.)

"MinCont" is a computer program that was developed in the 1990s as a convenient way of predicting the **Min**imum **Cont**act height anywhere in a bay of fixed-anchored OHW under some hot condition (typically 55°C). The lowest level of contact needs to still be greater than 4.57m (or 4.42m @ 45°C in certain City Underground tunnels).

The program requires the measurement of catenary & contact heights at each support location and at mid-bay, and catenary wire temperature at the time of measurements taken. It works by determining the change in catenary tension and thus sag with the hot temperature, which translates to the lower contact height at or near mid-bay.

This program should be routinely used in certain critical fixed-anchored areas to ensure reliable train running under conditions of extreme heat. It was originally written in the "C++" language for MS-DOS, but was later converted to run as an Excel spreadsheet. This had the advantage of also allowing a continuous run of OHW bays to be modelled (if needed) – which proved very handy many times. In fact, this approach was used for each bay of each wire run during the design of the Airport OHW, to help validate the design and so there would be no surprises at the end when constructed and operated.

CONTACT RAMP RATE

The change of contact height from one OHW support location to the next is referred to as the contact wire's *Ramp Rate*. This is sometimes referred to as "Contact Gradient".

It's important to note that the height is relative to the track (not horizon).

The rate-of-rise (or lowering) of contact wire is generally set at 1 in 300 for fixed-anchored OHW and 1 in 500 for regulated OHW, although this can be relaxed to some degree for slow speed traffic – refer to the current standards.

This restriction ensures that the train's pantographs can trace the contact wire and deliver uninterrupted supply to the train (with no arcing). It is also done to help ensure that the OHW is not disturbed so much as to cause it to wildly move about (especially at mid-bay), which helps get smooth current delivery at higher train speeds.

DYNAMIC OSCILLATIONS ("GALLOPING")

Somewhat related to the above *blowout* issue is the unusual phenomenon of OHW *dynamic oscillation* or "galloping", whereby the contact (and catenary) wires move wildly about under the influence of strong winds. This has much to do with harmonics and resonance,

established by wind blowing on the conductors and accentuated (amplified) by the presence of a series of equally spaced bay lengths.

In the late 1990s the (then new) regulated twin-contact OHW installed across Meadowbank Bridge (*Figure 68*) was observed on one particular day to be "flapping about" (as the train drivers described it), under the influence of strong, gusting westerly winds heading along Parramatta River. The wild movement of the OHW was perceived to be dramatic enough for train drivers to consider it unsafe to proceed across the bridge, which of course ended up delaying a number of trains. From memory, I think the trains ended up proceeding at slow speed (with caution), and they made it safely across to the other side. It's likely that the train's pantographs themselves would have caused the contact wire oscillations to dampen down (and in turn reduce the catenary oscillations also), making it safe to proceed.

Figure 68 - Meadowbank Bridge (with its deep and solid girders)

This was disappointing, as it was (and still remains) the best OHW system we have, in terms of high conductor tensions and ability to cope with high wind loads – we can't make the conductors any tighter (at 3:1 Safety Factor already).

Note that any disturbance on the contact wire within the bay can cause a disturbance to the catenary wire, and vice versa. Only at the support & registration location are the conductors well behaved (to a degree).

It is with this in mind that certain precautionary measures were put in place when designing and installing the new regulated OHW on the Sydney Harbour Bridge in 2010. This situation had similar bay lengths to those at Meadowbank Bridge, thus the concern.

It is thought that the problem at Meadowbank Bridge was primarily due to the large depth of the solid bridge girders (~2m or so), which likely caused huge areas of turbulence when the wind struck the girders and deflected up and over the bridge (some went under the bridge too). So instead of just a strong cross wind, there was also a turbulent updraft, causing the twin contact wires and catenary to flap about relative to each other, thus the train drivers' concern. Of course, it may have also been the gusting nature of the wind that caused or accentuated the problem.

I think the solution at Meadowbank was to install "150mm Contact Knuckles" at mid-bay of each bay, so as to more effectively keep the twin contacts together thorough each bay. The action apparently worked well, with no reported problems since they were installed (~ 20 years ago).

Although there appear to be big differences between the character of Meadowbank and Sydney Harbour Bridges (with the SHB seeming to have more "open" steelwork for wind to pass through), it was considered prudent to do whatever was reasonably practical to reduce

the likelihood of the OHW oscillating at high wind speeds. The SHB is higher above water level than Meadowbank Bridge, and as a result, is likely to witness larger wind speeds – even more concern.

Before the rebuild of the SHB OHW, it was noted that the old OHW showed evidence of a problem with strong winds. This is small wonder really, considering that the tension in the old fixed-anchored contact wire plummets under hot conditions. Even when it was eventually upgraded to the larger 193mm² size, the tension changes from its design value of 13.35kN at 21°C, to about 2kN at 55°C (see *Table 17*), which is a dramatic drop of 86%. This is very slack tension and is consequently very much influenced by the presence of strong winds. Indicators of past problems include the following.

- There were special pull-off arm *stop plates* (fitting 409/8) installed at each pull-off arm on the bridge itself (mostly between North and South Pylons). One of these stop plates is shown in the old fixed-anchored pull-off arrangement in *Figure 69* (which has since been replaced with a regulated pull-off arrangement). These plates acted to stop the arm and its connected contact wire from lifting more than about 100mm or 200mm, thus restricting any gross upward dynamic movement due to high winds when also hot.

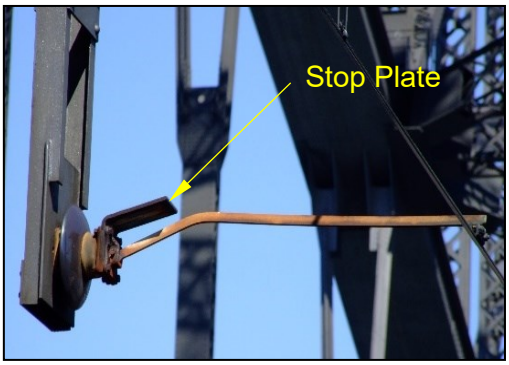


Figure 69 - Pull-Off Stop Plate

- On the bridge there seems to be suggestions that the original OHW bay lengths were reduced shortly after operation started in 1932, down to the existing 36m bays. This was most likely due to dynamic problems with high winds on hot days. But apart from some early newspaper record of an OHW event some time after its opening, there is no specific historic record we can readily draw on for further information about this situation.

In contrast with the old OHW across the Harbour Bridge, the new regulated OHW now has all 4 conductors – twin 165mm² catenaries and twin 137mm² contact wires for each wire run – installed at a constant high tension regardless of temperature (15.4kN in catenaries and 12.5kN in contacts). This is a vast improvement on the previous OHW. This has allowed the design bay lengths to be increased from 36m to 54m – supported where the special outrigged supports of the SHB occur.

It is normal design practice to maximise bay lengths, and this has the benefit of minimizing the amount of OHW support equipment (insulators, etc.) installed – and therefore needing to be maintained – on the bridge. However, even though the tensions are kept much higher, it is the *harmonics* that could possibly develop under strong wind conditions that can pose uncertainty to the stability of the OHW.

It is noted that the bridge height above water of about 50m will result in a 26% increase in wind speed at that level, and this needed to be taken into account in the design conductor blowouts. All bays were to be checked out for acceptable blowout, using the higher wind speed of 164km/h (instead of the standard 130km/h wind). The maximum blowout was to be less than 381mm from track centre to at least 1 of the 2 contact wires, i.e. average stagger of 381 + 150/2 = 456mm, was considered acceptable for pantograph security. Note that the amount of contact blowout in a 54m bay increases from 224mm @ 130km/h to 356mm @ 164km/h (i.e. an increased wind speed of 26% results in an increased blowout of 59%).

So, the actions on Sydney Harbour Bridge to reduce the likelihood of OHW galloping included:

a) Regulating the OHW and to the tightest tensions. (The standard twin catenary / twin contact OHW system achieved the high tensions already.)

b) There are 4 conductors instead of the original 2, and each conductor has a smaller diameter than before. (270mm² catenary replaced by twin 165mm² catenaries, and 193mm² contact replaced with twin 137mm² contacts.) This results in less wind loading per wire, which is a good thing (as well as optimal cooling after the wire passes heavy current).

c) Ensuring that no more than 2 or 3 consecutive bays had the same bay length (i.e. a couple of 36m bays, then a few 54m bays, etc.). This was considered to be one of the more crucial steps to help combat wire resonance and galloping.

d) Installing regular "ties" between the twin catenaries and the twin contacts – at least one tie per bay and located about one-third of the way into the bay, with the catenary tie located directly above the contact tie. Refer to *Figure 70*. The catenary tie was made using a cross-clamp on each catenary and a 300mm length of solid 193mm² contact wire bridging the 150mm space between catenaries. Likewise, the contacts were tied using a 100mm steel knuckle fitting with contact swivel clamps connecting the contact wires. Locating these ties one-third of the way in the bay again attempts to limit any chance of developing harmonic resonance in the bays of wire (and galloping). Although there's meant to be a 150mm horizontal spacing between the twin contacts, it was reduced to 100mm at these locations within the bay but 150mm at the arms. This was intended to minimise any tendency for rattling of the various 61/2 contact swivel clamp attachment fittings (especially the pull-off arms) which could otherwise wear the fittings out over time.

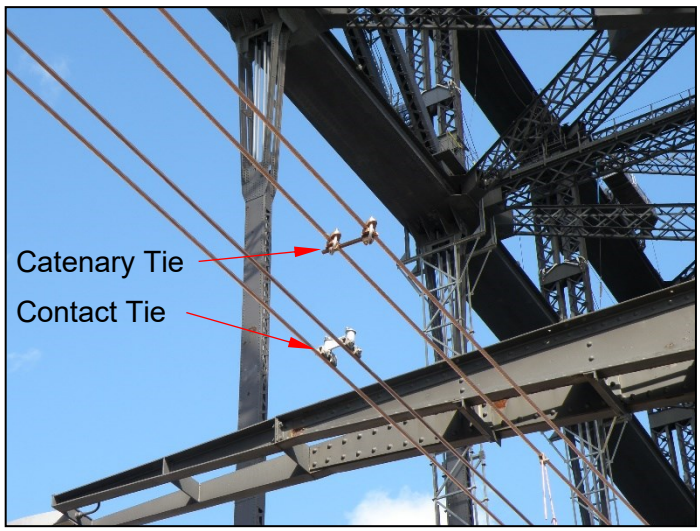


Figure 70 - Catenary & Contact Ties on SHB
(Photo: Steve Corbin)

To date, there have been no observed instances of galloping from the new OHW (fingers crossed).

KINKS

Contact wire *kinks* are instances on the contact wire where the wire was bent and is no longer straight in that area. Kinks can be formed during installation if the wire is bent for whatever reason. Refer to *Figure 71*. They can also be formed by the sudden impact onto the contact wire from other objects, such as a damaged pantograph or fallen trees.

Kinks are commonly located at pull-off arms where there's a reasonable weight placed on the contact wire. This is a particular problem for fixed-anchored contact wire when the tension plummets from a design of about 13kN (at 21°C) to around 2kN when hot. The lower tension causes the pantograph to uplift to higher levels through the bay and, when it suddenly comes to the heavy pull-off arm, the wire can become progressively damaged as the pantograph (with its inertia) is abruptly forced down near the arm.

Unfortunately, kinks prevent the pantograph from sliding along this wire in a smooth fashion, especially at speed. This can lead to supply interruptions to the train, and the resulting arcing can cause both the pantograph and contact wire to wear more quickly.

Once they've been established, kinks can be difficult to remove totally. They are normally repaired using a *kink block* and *copper mallet*. This block has a concave shape that allows the

kinked contact wire to be hammered slightly beyond its straight-line shape in order to ultimately become straight again, i.e. no more kink. However, it takes a lot of experience to get this right. I understand the striking face of the mallet is made from soft copper so as to minimise the any damage to the contact wire being repaired, but the more strikes that are given, the more chance there is of permanent damage to the crucial contact running surface.

Figure 71 shows a situation at North Sydney where the tight constraints of the tunnels has caused havoc with pantographs over the years (No.1 Tunnel). You can tell the space is tight because rarely do you see a clamp from the contact wire directly to the catenary wire without a dropper! (This clamp is not mentioned elsewhere in this document because it was used as a last resort in this extremely tight situation – its use results in a restriction and is definitely frowned upon!)

From memory, the damage was probably caused by a pantograph in grief, striking both catenary and contact wires. The strands of the damaged catenary wire were repaired using a wrap-on splice, but the contact wire had 2 kinks as the result of the incident (or maybe a few incidents), and they were never removed. Note the fresh splash signs of frequent arcing, shown by the tiny patches of copper colour under the contact wire and black carbon surrounding the area.

Kinks in the 193mm² cad-copper contact wire are notoriously difficult to remove, which is one of the reasons why this particular contact wire consist (size and metal) is no longer used. Refer to *A Contact Wire with a Problem* further down.

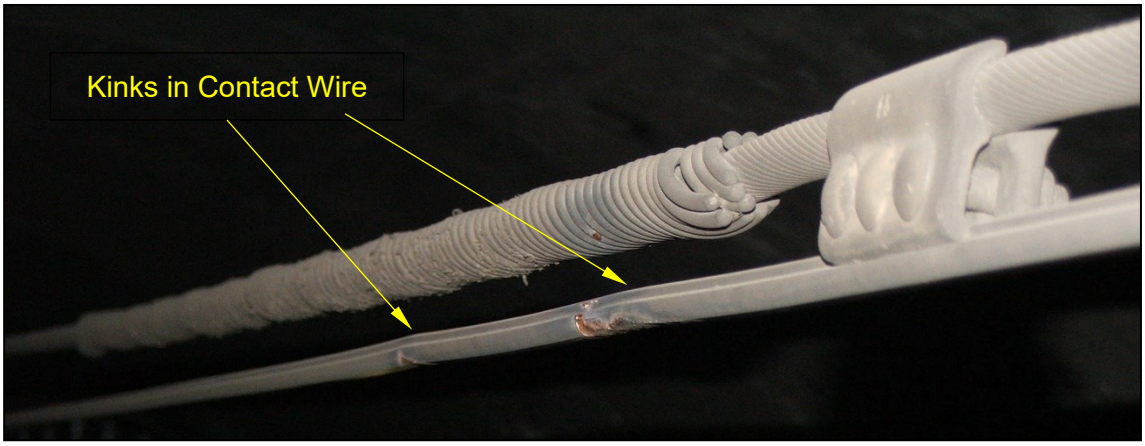


Figure 71 - Kinks (& arcing damage) on Contact Wire

CONTACT WIRE "MEMORY"

When the tension in the contact wire is released, it tends to take on its original coiled shape when wound onto a drum during manufacture.

This *memory* effect is most pronounced in cad-copper contact wire, which is a particularly hard metal, and especially in the larger 193mm² size. This wire is extremely difficult to straighten, even in short untensioned lengths such is those needed for *contact wear strips*. The Type 5 SI has 137mm² side runners which can also be difficult to get perfectly straight.

At high temperatures, the tension in a fixed-anchored 193mm² contact wire plummets from its design value of about 13kN (at 21°C) to around 2kN. At this low tension, unfortunately the wire can tend to exhibit the memory effect. The consequence (when hot) is a slack wire that behaves extremely poorly with pantographs on fast trains, by arcing and moving wildly about (especially under windy conditions).

A Contact Wire with a Problem

In 1967, and later on in the 1980s, it was acknowledged by certain experienced senior design and maintenance engineers, that in hindsight, the introduction of the 193mm² cadmium-copper contact wire was probably a big mistake for use in fixed-anchored OHW.

I understand it was initially introduced in the late 1950s by BICC (England), in order to provide more weight to counteract the high upward force of closely-spaced pantographs on freight trains. It also placed more copper in the air and thus improved the current carrying capacity of the OHW. Later on, this size could be (and was) installed throughout the network as an upgrade from existing 137mm² contact wire systems (if designed properly).

The reasoning against the 193mm² cad-copper (based on subsequent extensive experience) was that the larger wire diameter, coupled with the extremely hard nature of cad-copper metal, made it almost impossible to remove any kinks that may have developed in the wire. This metal is about as hard as bronze.

Apparently, many kinks were developed, often at pull-off arms, likely as a consequence of the large pantograph uplift at low contact tension (high temperatures). This was probably due in particular to the prevalence of heavy freight trains with multiple closely-spaced pantographs.

Once the kinks were in, they were extremely difficult to remove. (Note that the freight trains are no longer running.)

I quote the following from the "Liverpool – Campbelltown – Glenlee Electrification" report c. 1968 by A.R. Hamilton (Construction Engineer). This project proceeded well after the Compound OHW was installed (which had introduced this 193mm² cad-copper contact wire into Sydney's system) …

> "*In the past a 0.213in² (137mm²) cross section contact wire having a weight of 0.813lb/ft (11.87N/m) was in general use in the Metropolitan Area until trouble was experienced due to the upward pressure of four pantographs of two locomotives being so great that the weight of the wire would not prevent it being lifted excessively. To add extra weight a contact wire of 0.3in² (193mm²) cross section with weight of 1.157lb/ft (16.89N/m) was introduced. This improved conditions but experience has shown that this wire is so rigid that any kinks placed in the wiring during erection are very difficult to remove, with the result that excessive wear takes place on the wire by the pantograph bumping at the kink positions*".

As mentioned in the above section headed *Contact Wire "Memory"*, this particular wire exhibits a pronounced memory effect when the tension is low (hot), which can accentuate its poor dynamic performance at this high temperature.

Lastly, this larger contact wire size (193mm² compared to 137mm²) is slower to cool down. This is because of the larger ratio of cross-sectional area (which retains heat) to surface area (which helps remove heat), ultimately tends to store the heat longer than for smaller conductors, and this is not good (as discussed elsewhere).

Condemning Size

The contact wire is one of the few parts of the OHW that's subject to mechanical wear. This *frictional wear* happens over time as the pair of carbon strips of countless thousands of passing pantographs slide along the underside of the contact wire (collecting heavy current in the process, that then supplies the trains).

Because the contact wire wears, there must be a limit placed on the maximum amount of wear at which it needs to be either:

- *Locally repaired or renewed* – where there are a few discrete areas with a large amount of wear, e.g. near pull-off arms, but where the rest of the wire run is generally unworn, or
- *Totally renewed* – in the case of relatively significant and uniform wear throughout the wire run, or where the wire has an unacceptable number of worn areas or contact splices installed.

The *condemning size* of the contact wire is measured as the remaining thickness of the contact wire. Its actual condemning limit depends on the type of metal used in the contact wire, the applied tension and whether it is tensioned as fixed-anchored or as regulated tension. *Figure 55* gives an idea of the types of wear to condemning size.

Figure 72 - Contact measurement points

Figure 72 shows how measurement locations were sometimes set up for ongoing recording (showing measurement points "57" and "58" here, at Beverley Hills). Note however that the attachment of large surfaces onto the contact wire should be checked out regarding any adverse effects with wind, including added blowout and a tendency to rotate the wire if located well away from a pull-off arm.

Regulated Contact

With regulated contact wire, the applied tension remains relatively constant, regardless of how much the contact wire has worn. (The mass of the weight stack doesn't change.)

This means the stress in a worn contact wire increases with wear depth, i.e.
Stress = *Force / Area*, and the area decreases with wear.

It doesn't matter if the wear is uniform over the entire wire run, or if it's just localised – the tension remains constant (regulated), so the stress in these worn areas will increase, which can be a concern.

Note:
The *increased stress* in any worn areas of contact wire is one of the very few *adverse* aspects of a regulated tension OHW system. It is something that should be carefully considered during the life of the contact wire, because the wire must never become overstressed.

Fixed-Anchored Contact

With a fixed-anchored contact wire, if the contact wear is uniform over the tension length, the tension in the wire reduces as the wire wears, resulting in about the same stress in the wire, which is good.

Someone once mentioned an analogy that may help understand the nature of this fixed-anchored contact wire stress reduction.

> If you imagine the contact wire consists of 1,000 rubber band strands tied between 2 fixed ends, and with 1 Newton (say) in each strand. So 1,000N overall tension is developed between the fixed ends. Now if the strands in the bottom half are snipped (representing contact wire wear) then there's only 500 bands remaining, each with 1N tension (because

the ends haven't moved), so the overall tension is 500N, i.e. the tension is halved, along with the area, so the stress in the remaining part should be the same as it was.

The real problem however, occurs when most of the contact run is unworn but there are one or two locations with significant localised wear (e.g. at a few pull-off arms). In this case, the contact run still experiences the full high tension in cold weather, but these few locations of wear have reduced in cross-sectional size, resulting in increased stress in the worn wire at these points. Depending on the increased stress, it may eventually cause it to snap at one of these weakened points.

Important:
Extreme care should be exercised when attempting to *retension any fixed-anchored OHW*. If there is uniform contact wire wear throughout the wire run, then the tension will naturally reduce from its original design value. However, if the tension is then deliberately increased back to its original design tension, it may become *overstressed* at low temperatures (when its tension increases dramatically). This can be a trap for the unwary.

Remaining Wire Thickness

Generally speaking, regardless of whether it's fixed-anchored or regulated, the stress in a worn contact wire, due to its reduced (worn) size, should still have at least about 2:1 safety factor remaining. New contact wire under tension would typically have a minimum safety factor of more than 3:1 (The 3:1 SF normally sets how much design tension can be applied to the wire, bearing in mind that the higher the tension, the better the pantograph interface performance at speed.)

So, the minimum contact wire thickness remaining is usually set by the approximately 2:1 safety factor remaining – the so-called "condemning size".

The condemning thicknesses are given in the standards, along with policies that help manage the worn wire as it approaches this size.

The usual place for wire wear is at the bottom of the contact wire. However, at turnouts the contact wire can exhibit *side wear*, which is usually due to the stainless steel horn of an uplifted pantograph striking and rubbing against the side of the contact wire as it advances into the next track. (The contact wire eventually slides to the top of the pantograph where the carbon strips are located.) Sometimes the geometry of the OHW can be adjusted to minimise or remove any severe contact wear points. See *Figure 55*.

The introduction of carbon strip collectors on the top of all pantographs has dramatically decreased the wear rate of the contact wires. A typical contact life for fixed-anchored wire is now probably more than 20 years, and it is estimated that regulated wire has a life of 50 years or more (depending on other conditions). Indeed, word has it that the twin 137mm² contacts installed in the Liverpool to Glenlee Electrification in 1968 are apparently still there, and with good life remaining. But heavily trafficked areas likely reduce the contact life accordingly.

Poor Interface with Pantographs

The relatively poor life of fixed-anchored contact wire has much to do with problems with any non-ideal *profile* of the contact wire, notably as this wire and its supporting catenary wire change tension and shape with temperature.

Arcing and heavy wear points (hard spots at pull-off arms, etc.) can cause rapid deterioration of the contact wire in localised areas, and any repairs using contact full-splices and wearing strips can add to the problem over time.

See *Figure 73* for an example of multiple contact splices in a small area, although pairs of these would have been installed to splice out some 2m or so of damaged contact wire.

Note that the Standards give guidelines as to how many full-splices can be tolerated in the contact wire, before the wire needs to be renewed, or other action taken.

Contact wire *uplift* with pantograph upward pressure is another limitation. At low tensions and with the reduced weight of a worn contact wire, the amount of uplift can be so large as to allow the pantograph to clash with nearby components, such as cross-span wires.

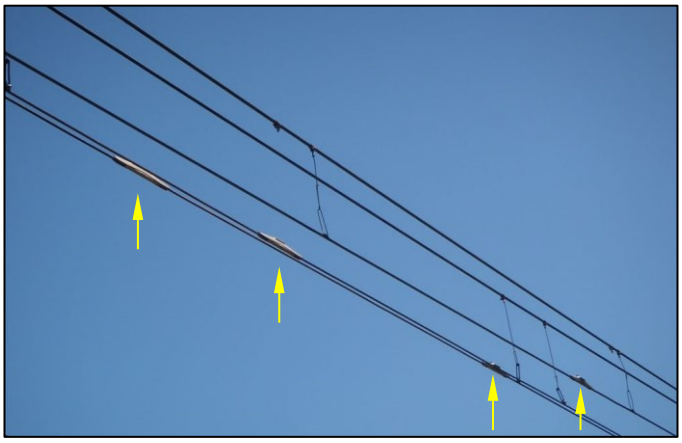


Figure 73 - Multiple Contact Splices in a Bay

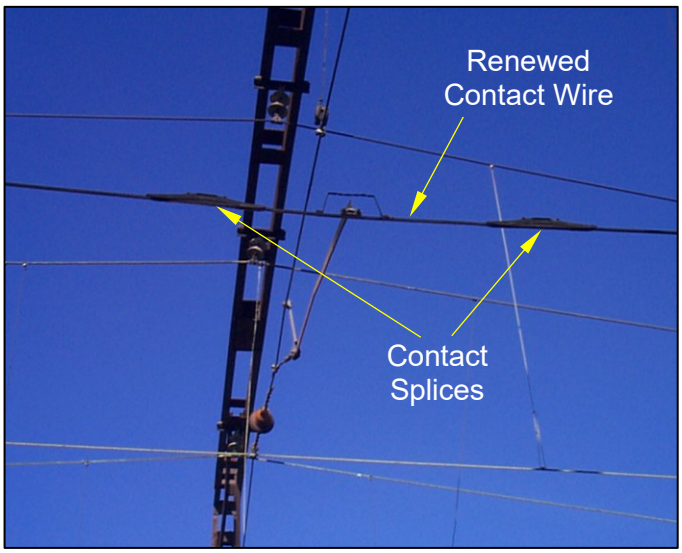


Figure 74 - New Contact Wire spliced adjacent to Pull-Off Arm

CONTACT WIRE RENEWAL

The contact wire should be planned for renewal if its uniformly worn thickness throughout the run begins to approach its condemning size.

Alternatively, the number of wear strips and/or contact splices can also help in the determination of when the economic life of a run of contact wire is up and therefore needs to be renewed. (This is fundamentally based on diminished reliability and pantograph interface performance.)

Refer to the Standards for renewal policy details.

THE ADVANTAGES OF TWIN CONTACTS

As mentioned previously, there are several distinct advantages of using twin contacts, rather than the single larger contact alternative. These advantages are discussed below.

Improved Pantograph Security

This is especially important under windy conditions (See *Section 6.3.2.2*).

For a single contact system, the in-running contact wire needs to always be within 381mm of the superelevated centreline of the track.

When designing with twin contacts, the stagger measurement is to a fictitious single contact position located midway between the two contacts, and the same 381mm rule applies to this

reference position. However, one wire is either 25mm (for 50mm contact spacing) or 75mm (for 150mm contact spacing) closer to the centreline of pantograph, and the other is that same distance further away from centreline. So, if the situation is at the limit of 381mm, then one wire will be either 25mm or 75mm less than the 381mm figure which is good. The other wire will be worse, but this probably doesn't matter so much because pantograph security is all about ensuring there's at least 1 contact wire controlling the upward pressure of the pantograph at all times.

Improved wear on the carbon strips of a Pantograph

There are 2 aspects here.

- Because there are now 2 contact areas that are separated by 50mm or 150mm, the wear is spread over a wider area of the carbon strips. E.g. 250mm stagger for a single contact places the wire at 250mm from centre of pantograph, whereas with twin contacts the wires are actually at 175mm and 325mm (assuming 150mm contact separation).
- Also, the upward pressure from the pantographs is halved on each contact wire, which tends to lower the wear rate on each contact wire and carbon strip area. It also helps by spreading this wear over a wider area on the little-worn portions of carbon strips.

Improved thermal performance

The normal single contact OHW system uses the larger 193mm² contact wire, whereas the twin contact system uses the smaller 137mm² contact wire size.

When the smaller wire heats up under a train's heavy load current, it takes less time for the wire to cool down before heating up again with a subsequent train. The higher thermal mass of the larger contact wire takes more time to cool, and this is a problem if subsequent trains passing through keep heating it up before it's had a chance to properly cool down. It could ultimately lead to overheating and annealing effects (wire damage). So, the smaller wire is better.

Improved current carrying capacity

Instead of a single contact surface, there are 2 surfaces, and each smaller (137mm²) contact wire can dissipate any generated heat better than a single larger (193mm²) contact wire.

So more current can pass between the twin contact wires and pantograph without causing overheating. See *Figure 67*.

More contact weight with a second wire

The added weight of the second contact wire helps to reduce pantograph uplift in each bay.

This was especially needed when 2, 3or 4 freight train consists ran, each with 2 pantographs up, which is a huge amount of upward force on the contact wire.

Even though freight trains no longer operate, the uplift on a single pantograph is also better controlled with the additional weight of twin contact wires.

TWIN CONTACT "CLASH" WITH HEAVY CURRENT

When twin, parallel, closely-spaced conductors pass heavy dc current in the same direction, they exhibit an electro-magnetic *attraction* force towards each other. (They repel if each the 2 currents are in opposite directions.)

The amount of attractive (or repelling) force increases with increased (current)² and also with decreased spacing between conductors.

This force of attraction can sometimes be on show with twin contact systems, where the wires are spaced only 50mm apart through a bay (or sometimes even with 150mm spacing) and *independent droppers* are installed to support each contact wire. These wires are physically kept apart at the pull-off arms at the ends of the bay, but unless there's something within the bay that can keep the 2 wires separated, they can sometimes come together with a *clashing* sound that can be heard some distance away.

This clashing action will more likely happen if a train suddenly applies full current to accelerate hard, or if a powering train suddenly enters a different electrical section. As the wires begin to come together, the resulting reduced spacing further increases the attraction force, and so makes a sudden clash more likely to happen.

Bays with *delrin bar* droppers (see *Section 3.1.3*) are less susceptible to this action, as the plastic delrin bar itself helps keep the 2 wires from coming together at every dropper location. With the maximum dropper spacing of only about 8m (with regulated OHW) or 5m (with fixed-anchored OHW), this regular spacing helps to ensure that no clashing will take place.

Apart from the sound, it's unlikely that this clashing will be a problem, unless the wires somehow tangle themselves amongst other hardware (such as dropper bottoms, in-span feeder clamps, etc.). However, I'm not aware of this being an issue in a regulated OHW system.

The main concern may be with fixed-anchored twin contact systems at low tensions (hot temperatures), that have 50mm contact spacing and which are supported by independent droppers. It's unlikely much of this configuration now exists.

If it becomes a problem, the most likely easy solution is to install a few 50mm steel knuckles within each offending bay to force the contacts to behave. Alternatively consider using the delrin bar dropper arrangement throughout the bay.

ARCING DAMAGE

Because heavy current passes between the pantograph and the contact wire, any momentary disconnection can cause significant arcing to occur.

This results in extremely bright flashes of light (that neighbours can readily complain about, especially when the arcing happens at night).

If the arc exists for more than about a second, it can melt significant portions of the copper, giving a reduced cross-sectional area in the immediate vicinity of the arc, as shown in *Figure 75*. It can also result in local annealing (softening) of the hard-drawn wire and subsequent loss of tensile strength, which is a real concern.

Figure 75 - Arcing damage to underside of Contact Wire

Because the contact wire is under a huge mechanical tension, this damage can be enough to lead to the wire drawing out, weakening and ultimately breaking, obviously with long-term impacts on train running.

In fixed-anchored OHW, sometimes the breakage won't occur immediately, but will happen later under some cold conditions when the contact tension increases dramatically. Or, it may happen as the contact wire wears further, compounding the problem.

In regulated OHW, such arc-related area reduction and/or annealing damage would more than likely lead to a higher risk of immediate breakage of the wire, because the tension remains at a constant high level (unaffected by temperature).

CONTACT WIRE MANUFACTURE

For many decades that know of, the contact wire was manufactured locally, at Port Kembla, NSW. (It may even go back to the early days of Sydney's electrification, since this factory first started manufacturing copper products in 1918.)

However, apparently the manufacturing business was sold, and I understand the new foreign (US) owners decided to stop production in their Wire & Rod division in 2013. This included the important contact wire manufacture.

So, after calling for global tenders for the future supply of contact wire, Sydney's supply now comes from overseas, e.g. currently (2014) from Germany – probably as far away as you can possibly get on this planet! Way to go, Australia!

Although this seems a real pity for a number of reasons, at least suitable replacements are now available for Sydney's 2 standard contact sizes, and in both hard-drawn and tin-bearing copper alloy – phew!

3.1.2.6 Status (c. 2014)

Cad-Copper contact wire is no longer being manufactured.

Current standard contacts are shown in the below table.

There seems to be a move to standardise on using only the tin-bearing copper alloy, as it can be used in both regulated and fixed-anchored OHW. However, for regulated OHW, its higher resistivity should be checked out against the economics of possible need for an additional substation or sectioning hut.

Contact Size	Regulated OHW	Fixed-Anchored OHW
137mm² (0.2 in²)	Hard Drawn Bare Copper or Tin Bearing Copper	Tin Bearing Copper
193mm² (0.3 in²)	Hard Drawn Bare Copper or Tin Bearing Copper	Tin Bearing Copper

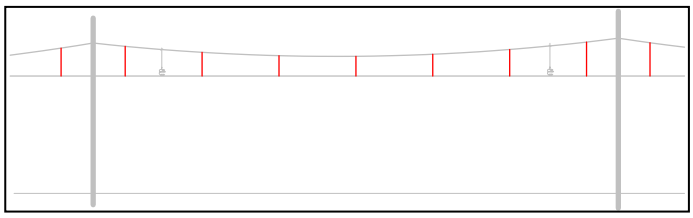
Table 19 - Current Contact Wires

3.1.2.7 Reference

See Table 8 for drawing references for each contact wire.

For more details refer to standard EP-08000024-SP, "Contact Wire".

3.1.3 Droppers



3.1.3.1 Description

Droppers are vertical lengths of solid copper wire, spaced at regular intervals of about 4.5m to 8m apart (depending on tensioning mode). They connect from the catenary to support and profile the contact wire in a bay of OHW.

Refer to *Figure 76* which shows a typical bay of droppers in an OHW system.

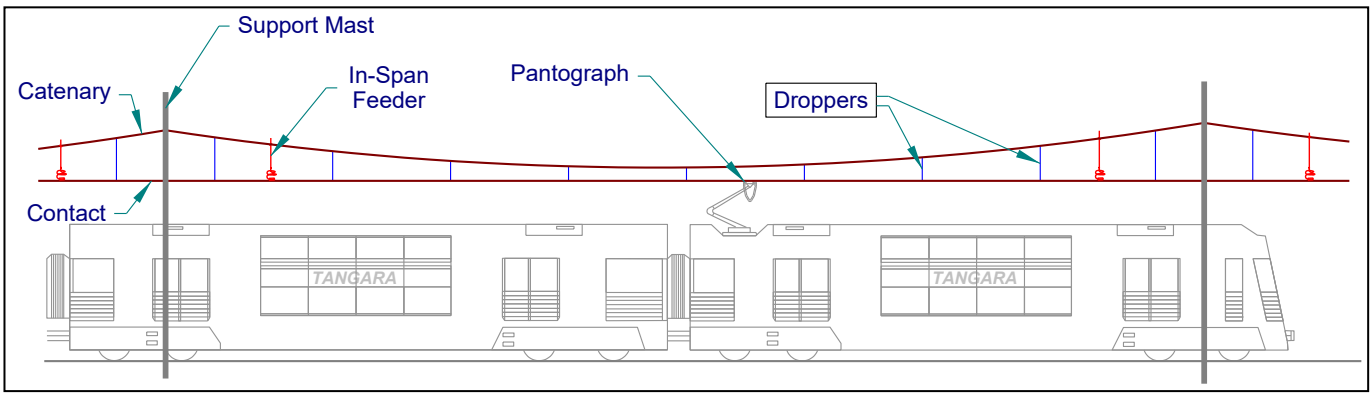


Figure 76 - Single Bay of OHW showing Dropper locations

3.1.3.2 Function

Droppers support the weight of the contact wire from the catenary wire located above.

They are installed in sufficient numbers and with each having appropriate length to allow the contact wire to take up a flat or near-flat profile throughout the bays of a wire run.

It is not the function of the droppers to feed current from the catenary to the contact wire – this function is performed by in-span feeders. However, in most cases some small current flows through the droppers, unless they are deliberately insulated from catenary and/or contact.

Note:

The current practice is to install a nylon insulated sleeve (fitting 95/31 or 95/32) onto the dropper to prevent current feeding between catenary and contact wires. The sleeve is capable of being retro-fitted, and is meant to be fitted to all droppers as a preventative measure.

3.1.3.3 Typical Components

The makeup of droppers includes 3 fundamental components (from top to bottom):

- The *catenary clamp* that attaches the dropper to the catenary wire.
- The *dropper* itself, made from solid copper wire, either 6.4mm diameter (older) or 5.4mm diameter (newer), and often comprised of a separate upper and lower loop fitting.
- The *contact clip* that attaches the dropper to the contact wire or wires (if twin contact).

The basic dropper components are shown in *Figure 77*.

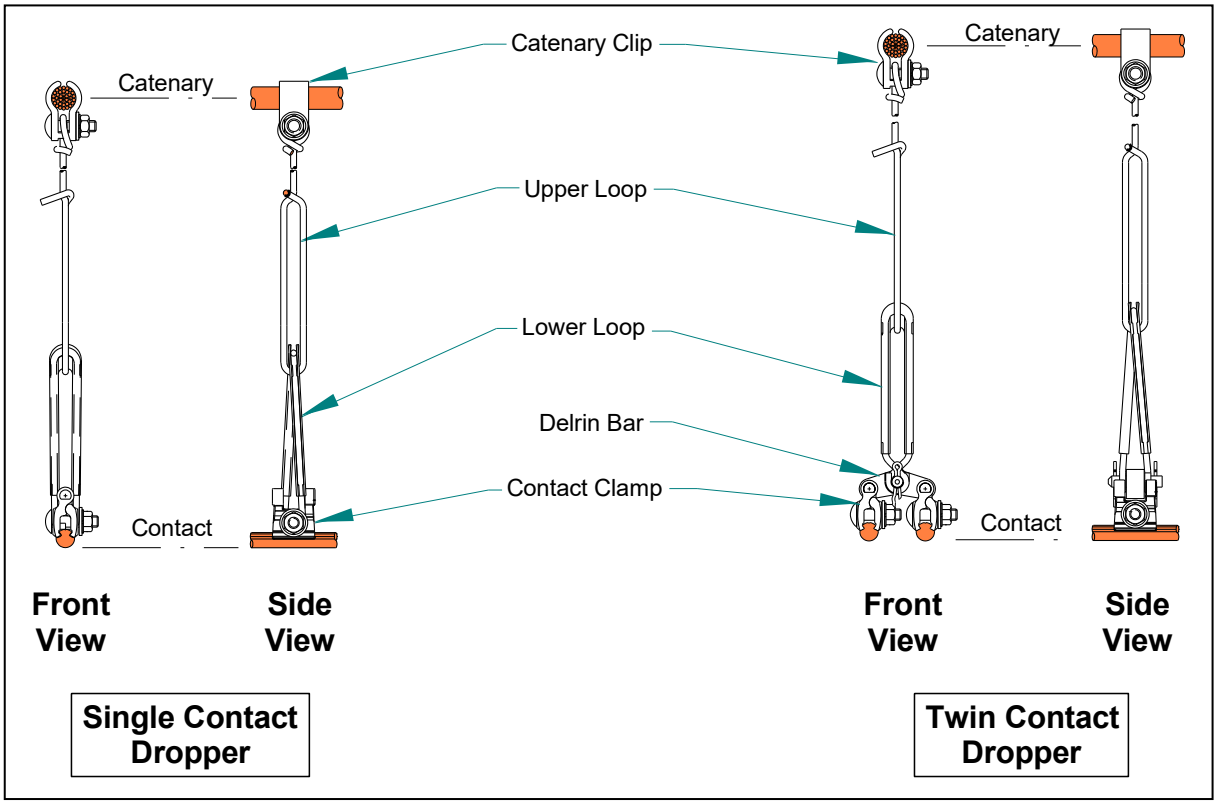


Figure 77 - Typical basic Dropper components

3.1.3.4 Configuration

CONTACT SUPPORT

A dropper can support 1 or 2 contact wires, as detailed below, and referring to *Figure 77*.

Single Contact Droppers

These droppers support 1 contact wire from 1 catenary wire.

They are typically used in a single catenary / single contact OHW system.

However, they can also be used in a single catenary / twin contact system, but only where the twin contacts are separated horizontally by greater than 50mm, i.e. typically 150mm standard. Droppers for this application are positioned 500mm either side of the theoretical single contact dropper position, on alternate contact wires (giving 1m spacing between pairs of droppers).

The droppers for a twin catenary / twin contact system are as per the single catenary / single contact system, apart from the actual dropper spacing in the bay, which requires that the dropper pairs be 1m longitudinally separated.

Twin Contact Droppers

These droppers are used in OHW with single catenary and twin contacts, where the contact horizontal spacing is set at about 50mm.

The 50mm contact spacing is best achieved using a "delrin bar" arrangement, as depicted in *Figure 78*. This includes an insulated (plastic) bar that separates the contact clips and spaces the contact wires by 50mm. This device is supported from the catenary by a standard single dropper.

Due to the "Delrin" (acetal resin) plastic, there will be no electrical feeding from the catenary to the either of the contact wires through this arrangement, which provides big advantages.

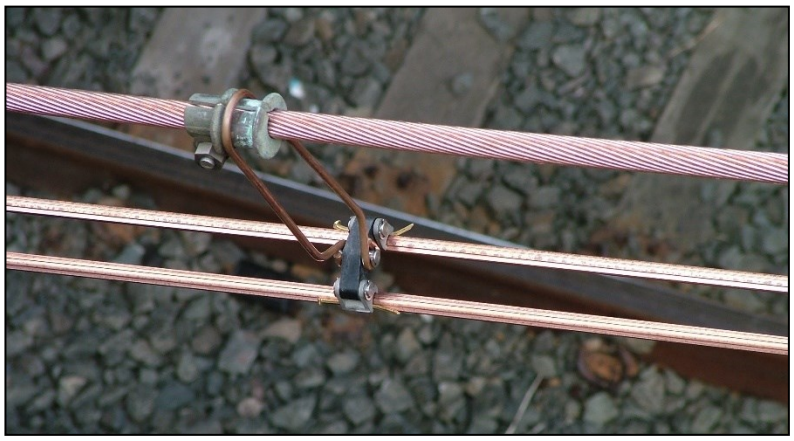


Figure 78 – Top view of a Delrin Bar Dropper

Delrin is easy to machine to shape, wears well over time, is relatively strong, tolerates UV radiation reasonably well, copes with relatively high temperatures and is an insulator – all properties that are beneficial to this arrangement.

DROPPER SPACING

Refer to *Figure 79*.

The formula for the number of droppers and their spacing in the bay depends mostly on whether they're installed in a regulated or in a fixed-anchored OHW system.

- ***Regulated OHW Droppers*** – The first dropper is typically located 4m into the bay, and subsequent droppers are evenly distributed in the bay (usually around 7m spacing), with the last dropper located again 4m from the end of the bay. (So, the spacing between last dropper of previous bay and first dropper in the bay is 8m.) The maximum dropper spacing through the bay is 8m (although I think this should probably be reduced).
- ***Fixed-anchored OHW Droppers*** – The first dropper is typically located about 2m to 2.5m into the bay, and subsequent droppers are evenly distributed in the bay (usually around 4.5m spacing), with the last dropper located again about 2m to 2.5m from the end of the bay. (So, the spacing between last dropper of previous bay and first dropper is normally about 4m to 5m.) Note that the Compound OHW system in the Blue Mountains has dropper spacing up to about 6m.

The actual spacing between droppers varies from bay to bay and depends on the bay length and the number of discrete droppers, but should not exceed their relevant maximum spacing, otherwise another dropper would be needed in that bay so as to reduce that spacing.

The more frequent droppering in a fixed-anchored bay is needed in order to reduce the amount of sagging of the contact wire between droppers when the contact tension is extremely low (at high temperatures).

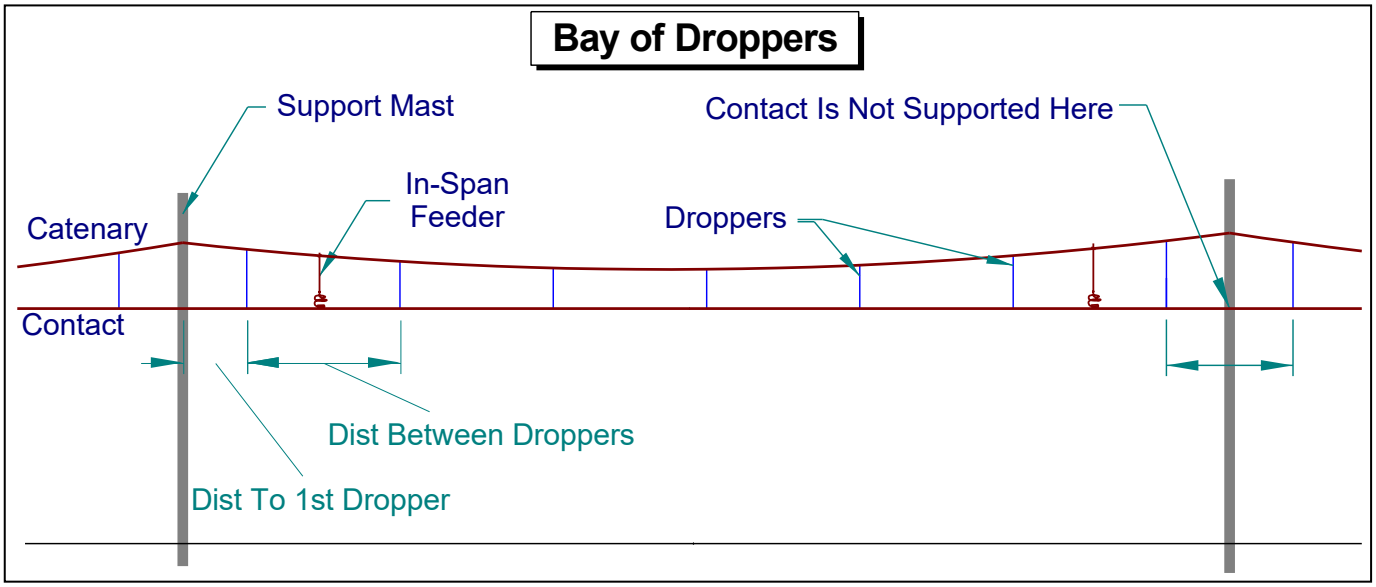


Figure 79 - Dropper spacing in a bay of OHW

DROPPER MAKE-UP

The majority of droppers are made each with an *upper loop* and a *lower loop* that are connected in series. This allows the contact wire/s to lift up as a pantograph passes, without bowing the dropper (which is somewhat tightly fixed to the catenary and contact wires). The 2 loops, moving up and down relative to each other, eliminate any metal fatigue in the dropper, although there may be some wear at this connection in time, unless protected in some way, i.e. using an insulated plastic sleeve.

The droppers are attached to the *catenary* by the following means:

- ***Half Moon & Shell*** – This is older arrangement that's not used much these days. The "Shell" is a small copper sheet that's shaped to install over the catenary. The "Half Moon" is a cast gunmetal half-moon shaped fitting which accepts the dropper and is attached to the shell. The bottom edges of the shell are twisted to secure the half moon.
- ***2 Piece Catenary Clip*** – This fitting consists of 2 gunmetal half-clamps which accept the dropper at the bottom, and these halves are then clamped around the catenary. A single cup head SS bolt is tightened to secure the fitting to the catenary. This can be seen in *Figure 77*.

For bays with shallow system depths (sometimes found inside tunnels and under overline bridges), there's no room for the 2-piece dropper, so only a single section of dropper wire is used in these situations.

In the old arrangement, the dropper lower loop is secured to the contact wire by means of a *contact clip and nail* arrangement – see *Figure 80*. The copper legs of the dropper lower loop passe through the 2 holes in the contact clip and are bent up to secure them. This clip is then placed loosely over the 2 notches in the top of the contact wire. A special brass nail (or "cotter") is then driven between the clip and one of the contact wedges, thus securing the dropper to the contact wire. The clip casting shows the correct direction for driving the tapered nail. Note that the nail should be driven into the clip

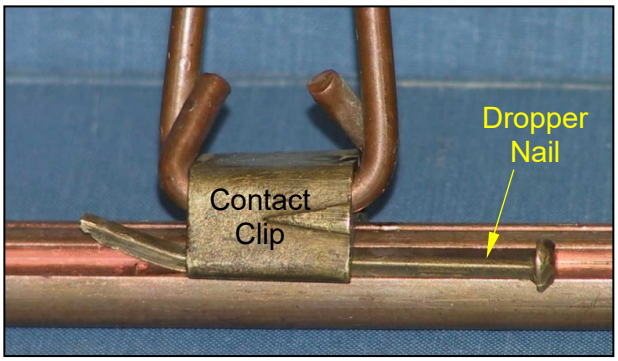


Figure 80 - Dropper Nail connection

in the direction of train travel, which may require the clip to be rotated 180°. The tapered end of the brass nail is bent upwards about 30° to 45° to secure the contact clip onto the wire.

In this configuration there are tight tolerances on the 3 connecting items: *contact clamp*, *contact wire* and *dropper nail*. If any of the 3 fittings is outside tolerance, then the connection can either be too tight or too loose – both situations are unacceptable.

In the new arrangement, the contact clip & nail has been replaced with a bolted clamp using fitting 95/30. This is a universal fitting in that it does away with virtually all of the multitude of previous types of contact clamps. It's suitable for both the 137mm² and 193mm² contact sizes, and is suitable for both the single dropper and the twin contact *delrin bar* droppers.

Note:

In any contact clamp arrangement, the shape of the contact clamp and its means of connection (with bent nail or bolted connection), are intended to clear the inclined pantograph horn where the contact wire needs to be "picked up".

A typical example of this situation occurs when pantographs traverse a crossover into a main line. The main line contact wire would typically be at least 50mm lower than the top of pantograph, thus exposing it to the horn of this pantograph and any main line droppers that may happen to occur in this forking-in point. Refer to *Section 5.1.29*, *OHW Design at Turnouts* for more of an idea of what this means, with relevant diagrams.

The various old styles of droppers are shown in *Figure 81*. Also, *Figure 83* provides a good summary of their various forms and the components that make them.

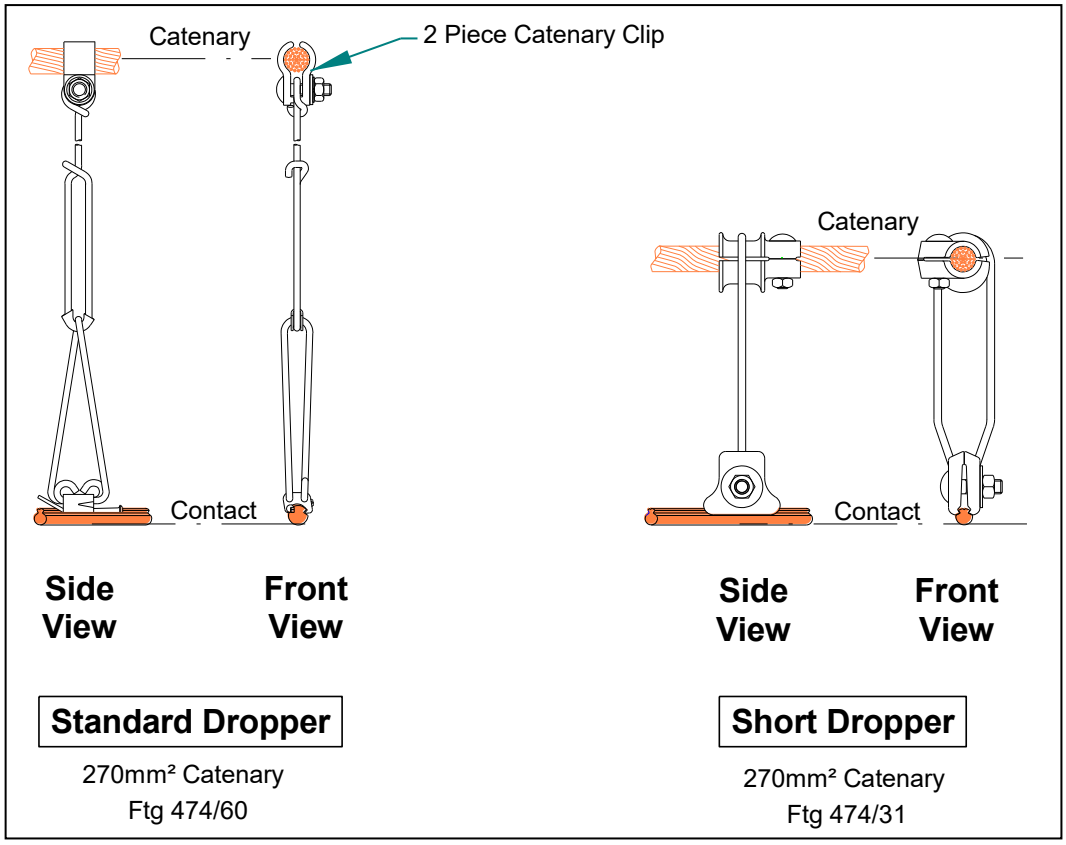


Figure 81 - Some basic old Dropper types (pre-2010)

The configurations and their make-up of the newer dropper arrangements, covering both single and twin contacts, are shown in *Figure 84*.

The following types of droppers are used:

- ***Standard Droppers*** – These are used in bays where the minimum distance between catenary and contact is greater than typically 350mm. This allows for the more desirable 2-piece arrangements with upper and lower loops. See left-hand side of *Figure 81*.
- ***Special Droppers*** (or ***Short Droppers***) – This type is used where the catenary to contact distance is below 350mm. They comprise a loop which is installed over the catenary and connects to the contact clip. The loop is available in incremental lengths. See left-hand side of *Figure 85*.
- ***Restricted Droppers*** – These droppers are used where catenary to contact distance is small and where contact uplift is to be restricted. They are similar in appearance to the *special dropper*, but incorporate a twist or other impediment in the loop below the catenary, to restrict unwanted contact uplift (mostly due to closely spaced pantographs on freight trains in fixed-anchored OHW). The loop is available in incremental lengths. They are sometimes installed at overline bridges. See right-hand side of *Figure 85*.
- ***Compound Droppers*** – These incorporate loop type droppers made from copper strip to support the contact wire from the auxiliary catenary. Droppers between the main catenary and the auxiliary catenary in the compound system are attached by half-moon & shells or 2 piece catenary clips. See *Figure 86*. Note that, unfortunately, this diagram is missing the special "aeroplane sleeve" that protects the auxiliary catenary, as shown much further on in *Figure 503*.

Figure 82 shows a special quality assurance "go / no-go" gauge that was used for checking the fit tolerances of the older contact clip for a particular size contact wire. Contact clip fittings are 95/16 and 95/17 for 137mm² and 193mm² contact wire sizes respectively.

As mentioned, the tolerances of all 3 items – the upper wedges in the contact wire, the dropper clip and the dropper nail – are all crucial, otherwise the driven dropper nail may be too loose to make a solid connection, or too tight to connect all 3 components together.

Of course, the good news now is that such a device is no longer needed with the new dropper clip arrangement, as its attachment bolt firmly clamps to the wedge in the contact wire, regardless of its size (137mm² or 193mm²) and the respective tolerances.

Figure 82 - Gauge for checking tolerance on old Contact Clip

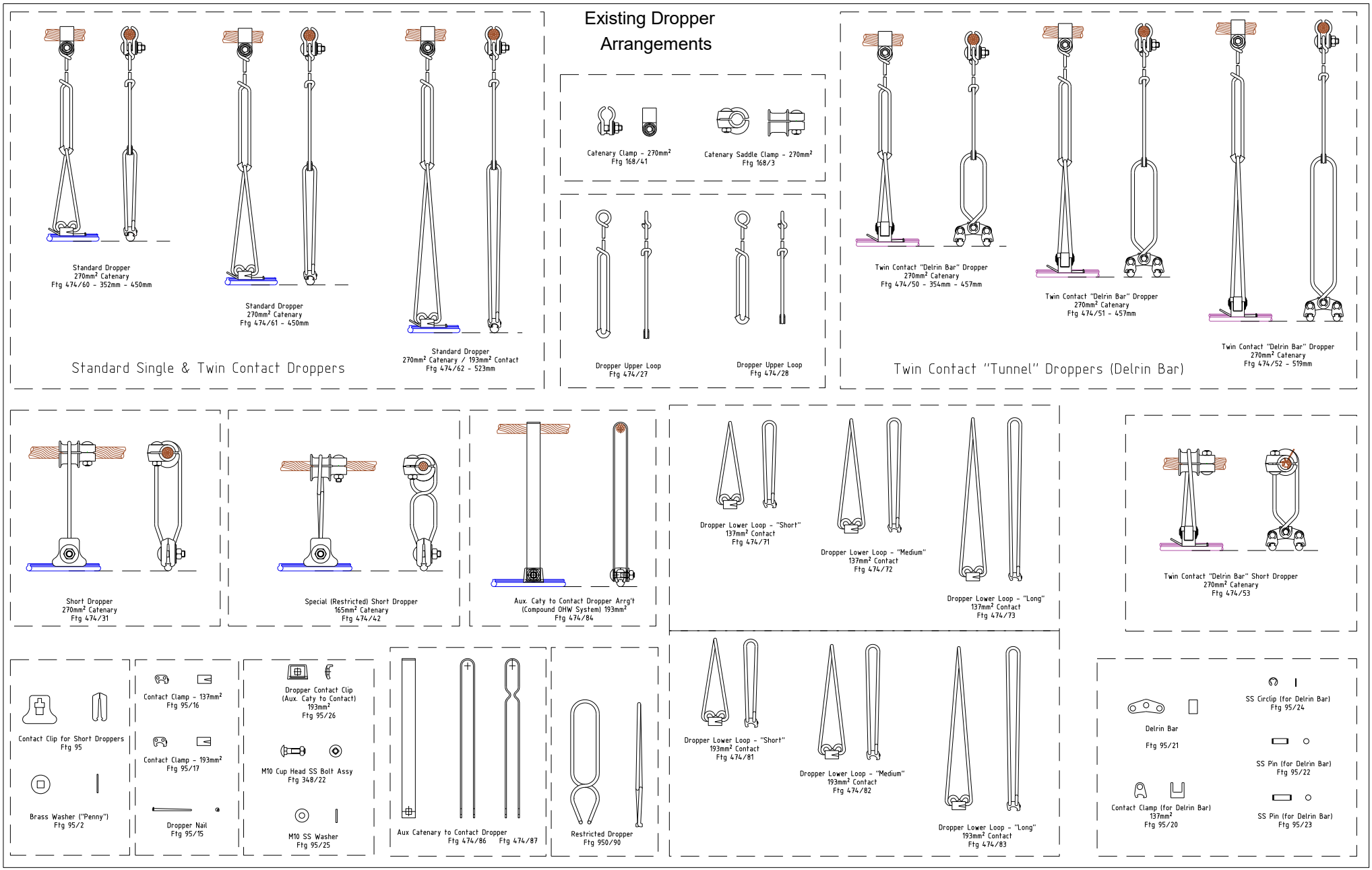

Existing Dropper Arrangements
Standard Dropper 270mm² Catenary Ftg 474/60 - 352mm - 450mm
Standard Dropper 270mm² Catenary Ftg 474/61 - 450mm
Standard Dropper 270mm² Catenary / 193mm² Contact Ftg 474/62 - 523mm
Standard Single & Twin Contact Droppers
Catenary Clamp - 270mm² Ftg 168/41
Catenary Saddle Clamp - 270mm² Ftg 168/3
Dropper Upper Loop Ftg 474/27
Dropper Upper Loop Ftg 474/28
Twin Contact "Delrin Bar" Dropper 270mm² Catenary Ftg 474/50 - 354mm - 457mm
Twin Contact "Delrin Bar" Dropper 270mm² Catenary Ftg 474/51 - 457mm
Twin Contact "Delrin Bar" Dropper 270mm² Catenary Ftg 474/52 - 519mm
Twin Contact "Tunnel" Droppers (Delrin Bar)
Short Dropper 270mm² Catenary Ftg 474/31
Special (Restricted) Short Dropper 165mm² Catenary Ftg 474/42
Aux. Caty to Contact Dropper Arrg't (Compound OHW System) 193mm² Ftg 474/84
Dropper Lower Loop - "Short" 137mm² Contact Ftg 474/71
Dropper Lower Loop - "Medium" 137mm² Contact Ftg 474/72
Dropper Lower Loop - "Long" 137mm² Contact Ftg 474/73
Twin Contact "Delrin Bar" Short Dropper 270mm² Catenary Ftg 474/53
Contact Clip for Short Droppers Ftg 95
Brass Washer ("Penny") Ftg 95/2
Contact Clamp - 137mm² Ftg 95/16
Contact Clamp - 193mm² Ftg 95/17
Dropper Nail Ftg 95/15
Dropper Contact Clip (Aux. Caty to Contact) 193mm² Ftg 95/26
M10 Cup Head SS Bolt Assy Ftg 348/22
M10 SS Washer Ftg 95/25
Aux Catenary to Contact Dropper Ftg 474/86 Ftg 474/87
Restricted Dropper Ftg 950/90
Dropper Lower Loop - "Short" 193mm² Contact Ftg 474/81
Dropper Lower Loop - "Medium" 193mm² Contact Ftg 474/82
Dropper Lower Loop - "Long" 193mm² Contact Ftg 474/83
Delrin Bar Ftg 95/21
Contact Clamp (for Delrin Bar) 137mm² Ftg 95/20
SS Circlip (for Delrin Bar) Ftg 95/24
SS Pin (for Delrin Bar) Ftg 95/22
SS Pin (for Delrin Bar) Ftg 95/23

Figure 83 - Most of the older styles of Droppers

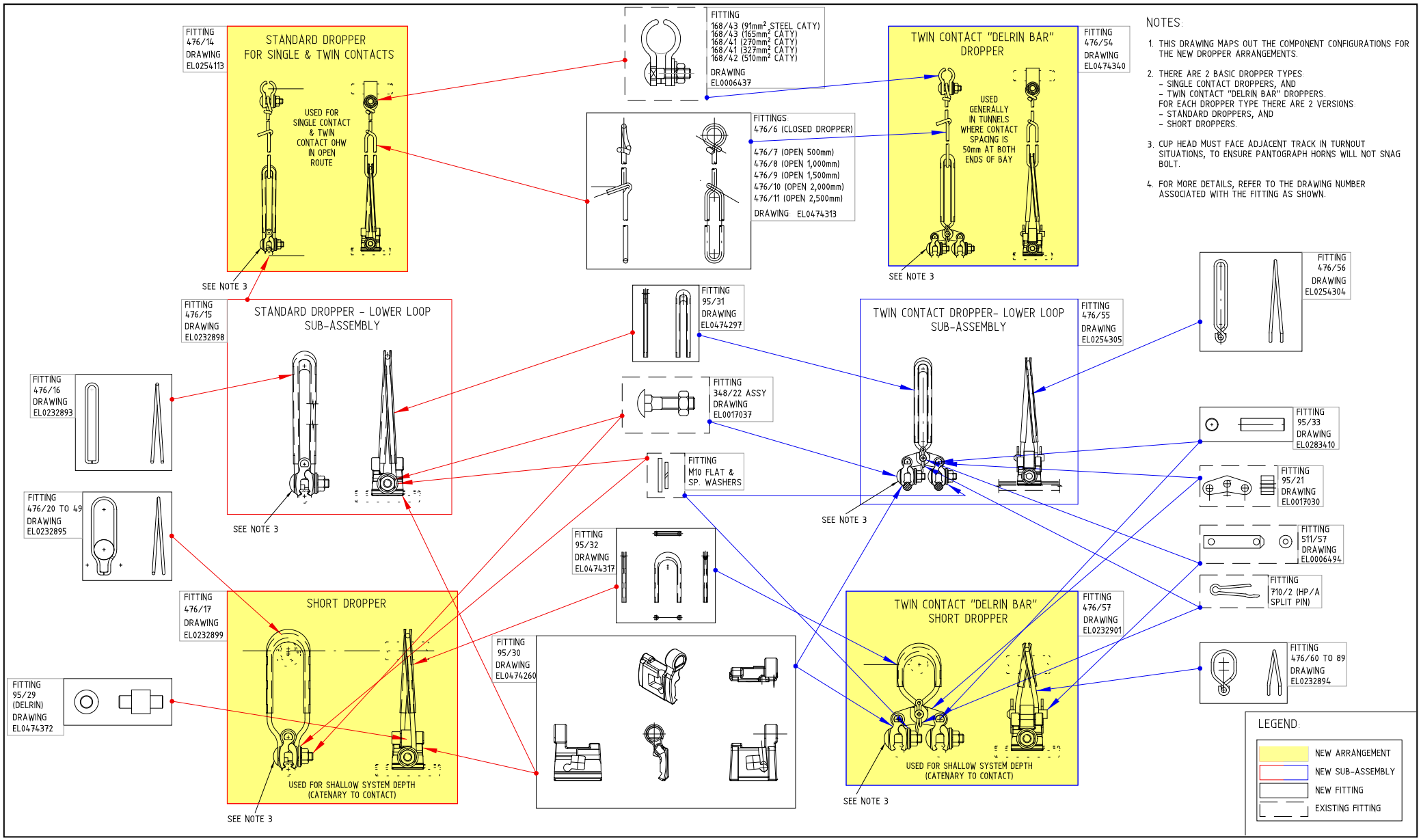

STANDARD DROPPER FOR SINGLE & TWIN CONTACTS
USED FOR SINGLE CONTACT & TWIN CONTACT OHW IN OPEN ROUTE
FITTING 476/14 DRAWING EL0254113
SEE NOTE 3
FITTING 168/43 (91mm² STEEL CATY) 168/43 (165mm² CATY) 168/41 (270mm² CATY) 168/41 (327mm² CATY) 168/42 (510mm² CATY) DRAWING EL0006437
FITTINGS: 476/6 (CLOSED DROPPER) 476/7 (OPEN 500mm) 476/8 (OPEN 1,000mm) 476/9 (OPEN 1,500mm) 476/10 (OPEN 2,000mm) 476/11 (OPEN 2,500mm) DRAWING EL0474313
TWIN CONTACT "DELRIN BAR" DROPPER
USED GENERALLY IN TUNNELS WHERE CONTACT SPACING IS 50mm AT BOTH ENDS OF BAY
FITTING 476/54 DRAWING EL0474340
SEE NOTE 3
NOTES:
1. THIS DRAWING MAPS OUT THE COMPONENT CONFIGURATIONS FOR THE NEW DROPPER ARRANGEMENTS.
2. THERE ARE 2 BASIC DROPPER TYPES
- SINGLE CONTACT DROPPERS, AND
- TWIN CONTACT "DELRIN BAR" DROPPERS.
FOR EACH DROPPER TYPE THERE ARE 2 VERSIONS
- STANDARD DROPPERS, AND
- SHORT DROPPERS.
3. CUP HEAD MUST FACE ADJACENT TRACK IN TURNOUT SITUATIONS, TO ENSURE PANTOGRAPH HORNS WILL NOT SNAG BOLT.
4. FOR MORE DETAILS, REFER TO THE DRAWING NUMBER ASSOCIATED WITH THE FITTING AS SHOWN.
FITTING 476/56 DRAWING EL0254304
STANDARD DROPPER - LOWER LOOP SUB-ASSEMBLY
FITTING 476/15 DRAWING EL0232898
SEE NOTE 3
FITTING 95/31 DRAWING EL0474297
TWIN CONTACT DROPPER- LOWER LOOP SUB-ASSEMBLY
FITTING 476/55 DRAWING EL0254305
SEE NOTE 3
FITTING 476/16 DRAWING EL0232893
FITTING 348/22 ASSY DRAWING EL0017037
FITTING 95/33 DRAWING EL0283410
FITTING 476/20 TO 49 DRAWING EL0232895
FITTING M10 FLAT & SP. WASHERS
FITTING 95/21 DRAWING EL0017030
FITTING 95/32 DRAWING EL0474317
FITTING 511/57 DRAWING EL0006494
FITTING 710/2 (HP/A SPLIT PIN)
SHORT DROPPER
FITTING 476/17 DRAWING EL0232899
USED FOR SHALLOW SYSTEM DEPTH (CATENARY TO CONTACT)
SEE NOTE 3
FITTING 95/30 DRAWING EL0474260
TWIN CONTACT "DELRIN BAR" SHORT DROPPER
FITTING 476/57 DRAWING EL0232901
USED FOR SHALLOW SYSTEM DEPTH (CATENARY TO CONTACT)
SEE NOTE 3
FITTING 476/60 TO 89 DRAWING EL0232894
FITTING 95/29 (DELRIN) DRAWING EL0474372
LEGEND:
NEW ARRANGEMENT
NEW SUB-ASSEMBLY
NEW FITTING
EXISTING FITTING

Figure 84 - Mapping of all new styles of Droppers

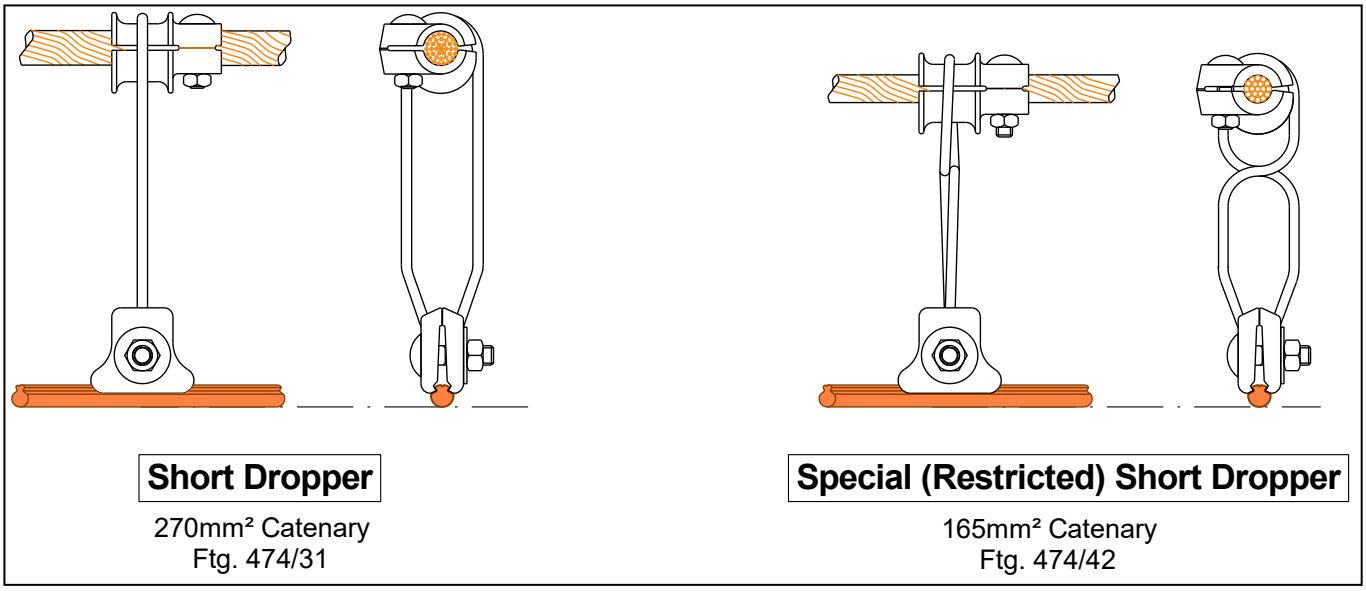


Figure 85 - Older Short (left) and Restricted (right) Droppers

DROPPER INSULATION

The dropper itself is made from hard-drawn single-stranded (solid) copper wire of about 5mm to 6mm diameter.

The decision to use copper in this situation was likely made early on in Sydney's electrification (likely because that's what the British system used at that time?). It was probably based on the understanding that the dropper had to be able to pass some small-level dc current during service (notably when a pantograph was near), as this was a consequence of there being no convenient way to insulate each dropper to prevent such current flowing – this is even though each bay had 1 or more in-span feeders for just that purpose.

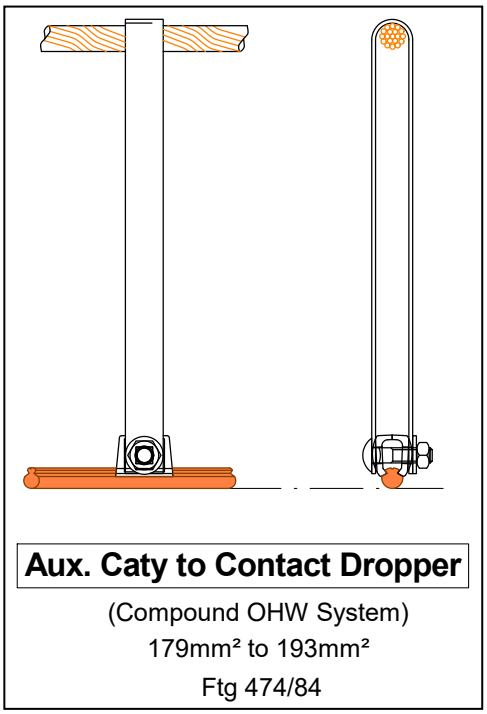


Figure 86 - Compound OHW Dropper

Copper was probably the most readily available and appropriate metal to use for this purpose back then. But over the decades as the train loads grew (currents increased), and train population and train services became increasingly more frequent, the droppers began to be seen as a "weak spot" in the OHW system. In particular, the low conductor tensions at hot temperatures in the old fixed-anchored OHW, resulted in significant pantograph uplift, especially with the closely-spaced pantographs of the freight trains in operation until the 1990s. A larger amount of uplift resulted in more significant wear on the droppers, particularly when they were feeding current as well.

So, insulating the droppers with a special clip-on sleeve, was seen as a way to minimise any wear and thus extend their life. Some droppers, such as the twin-contact "Delrin Bar" droppers in use since the 1970s, inherently provided such insulation.

All new dropper standard arrangements come with some form of insulation to prevent the droppers from feeding. But this means the in-span feeders will need to work harder.

3.1.3.5 Design Notes

Dropper Wire Makeup

Droppers can be made up of a single-piece or 2-piece arrangement.

From the early days of electrification the droppers used in Sydney's OHW system were generally of 2-piece makeup, consisting of an *Upper Loop* and a *Lower Loop*. This is the current situation too.

A single-piece dropper, of discrete lengths, was reserved for shallow system depths where there wasn't sufficient space for including the upper loop. The situations typically include areas leading to and under overline bridges and sometimes within tunnels. The single-piece dropper applied to anything less than about 350mm from contact vertically up to the supporting catenary wire.

The intent of having a 2-piece dropper is to allow for some large degree of contact wire uplift (without the catenary moving up the same amount), without causing fatigue somewhere in the dropper arrangement. In this case, the upper and lower loops can disconnect as the pantograph passes through, and then resupport the contact wire back at its correct level. This freedom between upper and lower loops prevents any other part from fatiguing in time. But the loops must not bear heavily against each other during this movement, otherwise they may wear over time.

The uplift problem is only a big issue with fixed-anchored OHW when the contact tension is low (at hot working temperatures). And it takes place more for those droppers located close to the catenary support points at each end of the bay, because the catenary cannot rise here when the contact wire lifts as its weight is supported by a passing pantograph.

Note that there are other options, used around the world, for just using single-piece droppers, including droppers made from braided wire. I understand the braiding of fine copper strands can more readily cope with flexing without causing fatigue. (The flexing is again brought about by pantograph uplift as it passes through.) I guess in the early days of electrification, braided copper wire may not have been available, or thought of as being a solution to the fatigue problem.

New Contact Clamp – Fitting 95/30

This clamp (or "clip") was designed in 2009 to be a universal clamp that fits both the 137mm² and 193mm² contact wire sizes, and installs on all dropper arrangements. Its design was developed in 3-D CAD, and the complex shape ideally required casting in a Computer Aided Manufacturing process, in stainless steel, with the final item heat treated and passivated to prevent stress corrosion. See *Figure 87* which is an early prototype (which is only slightly different to the final product).

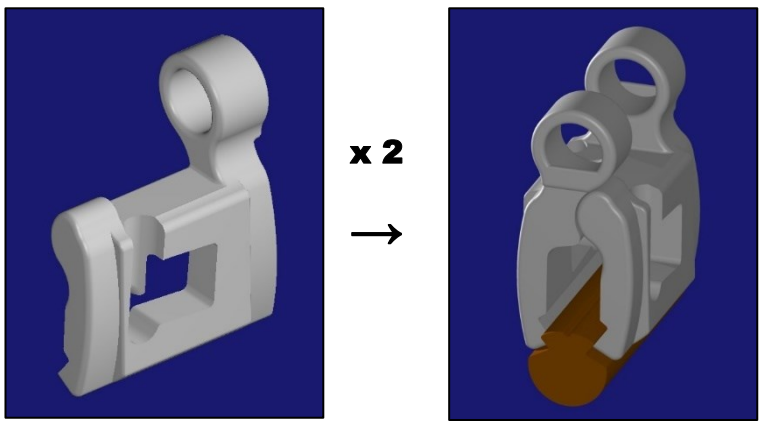


Figure 87 - 95/30 Dropper Clip (2 required)

The dropper clip uses 2 sides made from the same casting die. A standard stainless steel cup-head bolt (fitting 348/21) passes through the square recesses one-third the way up the casting, which traps the square neck of the bolt head. The nut (fitting 348/20), spring washer and

washer (fitting 95/25) then tighten, which clamps both clip sides firmly to the contact wire groove, as required.

Features of the new dropper clip include:

- Only a single casting die is required. The clip arrangement uses 2 of the cast pieces.
- The clip is secured to the contact wire using a standard cup-head stainless steel bolt. The square neck of this bolt is trapped in the square hole of the clip, requiring only one spanner to tighten the nut.
- Stock inventory is simplified (6 stock items eliminated).
- Eliminates choosing the wrong clip for a particular contact wire size when on site.
- In the twin contact *delrin bar* arrangement, there's no need for installing stainless steel "C" circlips onto 10mm stainless steel pin (these had been an installer's nightmare). Instead, the 10mm pin is captured in the top housing of the new clip.
- The clip is a relocatable and reusable item.

So, the clips can connect the contact wire/s to the dropper in 2 ways:

- Using the standard 5.38mm solid copper dropper wire, which is bent 90° at both bottom ends for a short distance, and fed into the hole and vertical groove on the side of each clip. The design is such that tightening the nut & washer on the cup-head bolt presses the copper dropper wire firmly against the casting, leaving a small gap between cup head and casting on one side, and washer and the other casting on the remote side. Hence, in this 3 component system, there is no loose connection, ensuring the longevity of this connection.
- Using a 10mm diameter SS pin installed into the 2 top loops provided in the clip casting. This configuration is used in the twin contact "delrin bar" dropper. When inserted, the 10mm pin becomes trapped by the small flat lips located on the bottom at the end of each hole. This means there's no more need for installing the 2 fiddly circlips of the previous arrangement.
  Because the 2 clip halves hinge half way up, the inserted 10mm pin at top can only be properly aligned for one size contact wire installed at the bottom of the clip, and so it has been optimised for the smaller 137mm² size (which is the only size needed in this twin-contact dropper configuration anyway).

Figure 88 - New Dropper Clip for Single Contact (left) & Twin Contacts (right)

NEW DROPPERS

In 2010 various new dropper arrangements were rolled out in conjunction with the introduction of the above new dropper clip (95/30). This clip had been in development over a number of years and had been field trialled at various locations for considerable time with good results.

The limited number of new dropper arrangements were to supersede the plethora of other dropper types used up until then (with some dating back to the early days of electrification). These arrangements are categorised in *Figure 84*.

There were 2 main drivers for the new dropper arrangements were:

- Because of ill-fitting dropper nails (which wedge the contact clamp to the contact wire). The tolerances of the contact wire, the contact clamp and the dropper nail had to all be closely matched, otherwise the nail would not fit properly (it was either too loose, or so tight that it could not be driven in far enough to be bent up & secured).

- The need to prevent heavier feeding currents from passing through the droppers, to stop spark erosion & failure. Special plastic sleeves were introduced for this purpose, which could also be retro-fitted to the older arrangements.

The new droppers have the following important differences:

- A new stainless steel contact clamp (95/30) was developed to replace all other existing types of contact clamps.
- This contact clamp is a bolted clamp, so there's no need for the dropper nail (with all its consequential adverse tolerance issues). The clamp comprises two identical castings which are bolted together, and it attaches to both standard contact wire sizes – 137 & 193mm².
- The contact clamp can be connected to the dropper using either:
  - a solid copper wire connected to the sides of the clamp – in single contact droppers (see left-hand side column of *Figure 84*), or
  - a pin connection at the top of the contact clamp – for connection to the delrin bar in the case of the twin contact arrangement (see right-hand side column of *Figure 84*).
- There is now only 1 length of lower loop in the standard dropper (instead of the previous 3 lengths – small, medium & large).
- All new lower loops incorporate special insulated sleeves, to prevent traction current passing through the dropper with consequential spark erosion & premature failure of the dropper wire. (Increasingly heavy traction currents have driven this decision.)
- For both the standard Single Dropper and the Twin Contact Dropper arrangements, there is a Short Dropper version to cater for shallow system depths (between catenary & contact) of less than about 360mm. The dropper loops for Short Droppers are in 10mm increments and are suitable for all 6 Catenary sizes – 165, 179, 270, 327 & 510mm² and 7/8 SWG steel.
- The Short Droppers no longer require the large & heavy catenary "saddle clamp" for connecting the dropper to the catenary.
- The "delrin bar" dropper arrangement for twin contacts no longer requires the fiddly installation of circlips – the 10mm stainless steel pin is now simply trapped within the top of contact clamp. Also, the connection to the dropper wire now uses the standard hump-back split pins which are easier to install than circlips.
- The dropper upper loop no longer requires the special "prawn" fitting installed at the bottom (which was a sacrificial item to reduce wear), but instead now relies on the plastic insulated dropper sleeve to more effectively prevent current feeding and wear.
- The new droppers can be incorporated into the Compound OHW system (Blue Mountains) as well as the "Simple Catenary" systems. In Compound OHW, droppers from the auxiliary catenary to contact no longer require the use of the special copper protective "aeroplane sleeve" fitting installed on the auxiliary catenary, as shown further on in *Figure 503*.
- If the contact wire shifts longitudinally relative to the catenary, this misalignment will not be reflected into the loop style droppers, i.e. the droppers will remain vertical. (Note – this non-vertical dropper alignment used to be a tell-tale sign of something wrong, so now need to rely on some other approach.)
- For extremely shallow system depths less than 110mm, the Single Contact Short Dropper includes a delrin "stopper" to be installed in the top of the contact clamp to prevent the catenary from electrically touching the top of it with pantograph uplift.
- Only one size of dropper wire is required – 5.38mm diameter solid copper, instead of the current 2 sizes, 5.38mm and 6.4mm.
- There is no more need for "Restricted" droppers. These were necessary to limit the fixed-anchored contact wire uplift under hot conditions, resulting from the multiple closely-spaced pantographs of electric freight trains.

- (The standard dropper catenary clip currently in use remains.)

CONTACT PROFILE WITH PRESAG

As described in *Section 3.1.2.5*, "presag" involves a process of deliberately lowering the contact wire a small amount towards the middle of the bay in a regulated OHW system (sometimes referred to as contact "bellying"). See also *Figure 57*.

When applied, the amount of presag at mid-bay is given by the formula:

Presag = BayLength / 1,000

So, a 67m bay should have 67mm presag, (which is the difference in level between a string line from first to last droppers, vertically down to the contact wire at mid-bay.

This presag improves pantograph performance at high speed, by essentially aiming to keep the pantograph at a constant level throughout the bay. This in turn is intended to deliver uninterrupted power to the train without any arcing. (The design of the modern pantograph helps to achieve this outcome too.)

Actually, achieving the correct amount of presag in a bay involves calculating droppers of appropriate length through that bay. This is complicated, as it involves determining the redistribution of dropper weight loads held by the catenary, with each dropper supporting the weight of different portions of the contact wire (i.e. from contact wire low point to next low point).

Dropper lengths to achieve presag can be calculated using bending moments. This really demands a fairly sophisticated computer program to work them out accurately. They are preferably calculated for the entire run of bays, because contact low points can appear in the next or previous bay.

CONTACT PROFILE WITH "HOG"

A contact wire exhibits "hog" if its height increases towards mid-bay. See *Figure 57*.

Sometimes hogging is applied to keep the contact wire parallel to the track in a vertical curve. This can be done in tight tunnel situations, where the peak in the track curve might otherwise reduce the already low contact height. The fixed-anchored OHW inside the Airport Line was designed to incorporate such hogging because otherwise the contact height under hot temperatures may have come close to encroaching the 4.57m absolute minimum height figure under worst-case conditions.

The complex calculations for determining the dropper lengths that deliver accurate hog are quite similar to that for presag. The dropper program should be able to handle both hog and presag situations, ideally for the entire wire run from anchor to anchor.

DROPPER SPACING

The space between droppers depends on the form of tensioning the OHW conductors: *Regulated* or *Fixed-Anchored*. See *Figure 89*.

Because the tension is kept constantly high in regulated OHW, the dropper spacing can be relatively large (up to about 8m).

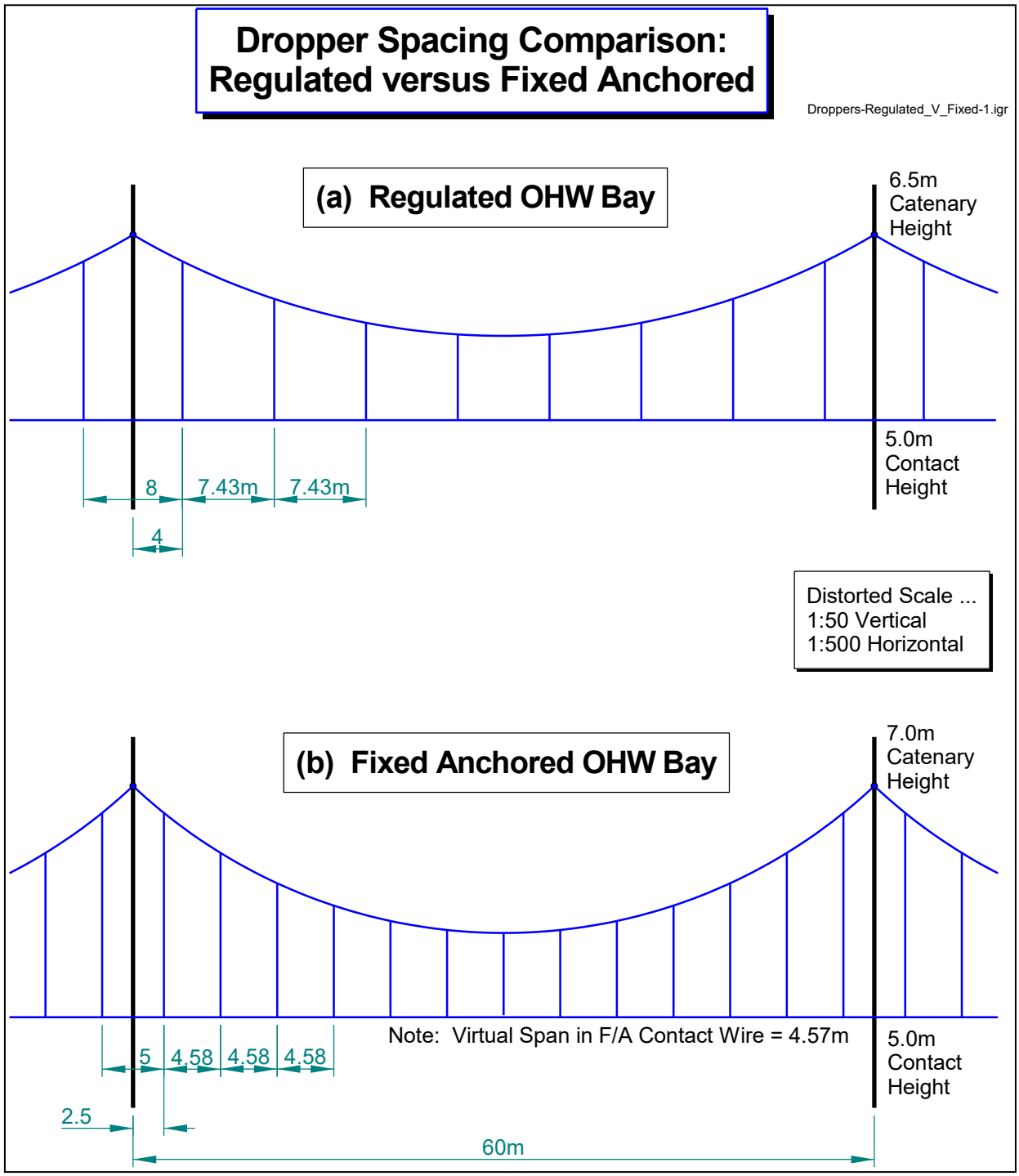


Figure 89 - Comparison of typical Dropper Spacing – Regulated versus Fixed-Anchored

However, in fixed-anchored OHW the tension plummets under hot conditions, so the dropper spacing needs to also be reduced, otherwise the contact sag between droppers would be intolerable for reliable train operations. Experience has shown that a spacing of about 4.57m (15 foot in the old measure) works well enough.

The horizontal distance from catenary support location to the first dropper in the bay is usually about half the normal dropper spacing (i.e. 4m for regulated and about 2.5m for fixed-anchored OHW). The same applies to the last dropper in the previous bay. So, the distance between these droppers is about the same as all other successive droppers in the bay.

The actual *spacing between droppers* depends on the bay length and the number of droppers in the bay. So, if adjacent bay lengths differ, then so do will the spacing between droppers (although the distance to first and last droppers is usually kept constant).

Dropper Spacing is given by…

$$D_b = \frac{L - 2 \times D_1}{N_d - 1}$$

Equation 4 - Dropper Spacing

Where:

D_b = Distance between droppers (m)

L = Length of bay (m)

D_1 = Distance to 1st dropper (m)

N_d = Number of droppers in bay

Dropper Spacing in Fixed-Anchored OHW

Fixed-anchored droppering is constant throughout the entire wire run from anchor to anchor. This is because it would otherwise suffer from unacceptable amounts of sag under the low tensions resulting at high temperatures – indeed there are sag problems with both the catenary and contact wires.

Dropper Spacing in Regulated OHW

Unlike fixed-anchored droppering, those for regulated OHW can be dependent on the type of bays, as typically shown in *Figure 90*:

- ***Normal bay*** – this is where the OHW is in-running (IR) at both ends of the bay. Normal dropper spacing applies.
- ***Overlap bay*** – this is where one end of the bay is in-running and the other is brought out-of-running (OOR).
  Past practice was to only dropper that portion of the bay that needed the contact wire to be supported for its flat profile. This was done in order to get the contact wire up as quickly as possible to its OOR height, which maximised the overlap length – generally a good thing.
  However, *recent preference is to dropper the entire bay*, even though part of the bay may have droppers that rattle (because they don't support any or much contact wire weight). I think this change is probably for the good, especially if the regulated tension changes dramatically (for whatever reason).
- ***Pennant bay*** – this is where the OHW is out-of-running (i.e. they become pennant wires), usually heading directly or eventually to anchor.
  Past practice was to only install about 3 droppers in the bay (enough to keep the contact wire up and well clear of the in-running wire).
  Recent practice is to *install full droppering* (as it's probably not worth the risk).

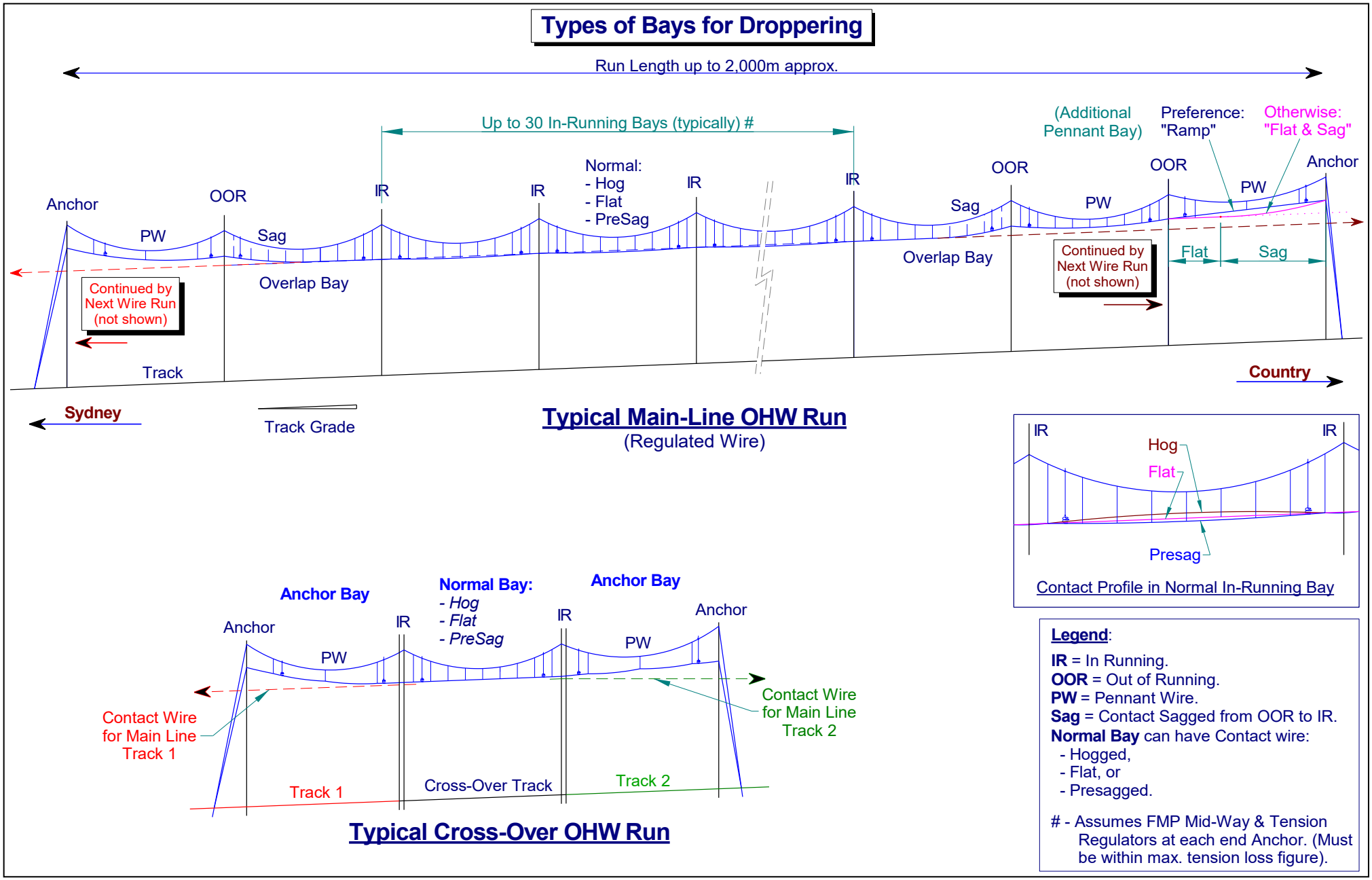


Figure 90 - Types of Bays (identified for different Dropper spacings)

DROPPER PROGRAMS

There are a few computer programs that have been developed over time to calculate bays of droppers, for both fixed-anchored and regulated tension OHW systems.

Refer to *Section 8.3* which shows some of the dropper programs that were (and probably still are) currently available.

In about 2012 I was asked to develop yet another a dropper program, but this one was written in Visual Basic for Excel and was intended to calculate droppers for the entire wire run. It was to be included in the roll-out of the new dropper arrangements at the time, including the newly developed universal contact clip fitting 95/30. I found out this was simple in principle but complex in execution, for a program that accurately models all droppers in each bay. The following are some of the desired outcomes of the program.

- Driven by OHW run data that's entered into the CCalc Input Sheet, in spreadsheet format. Click a button and the Visual Basic program (residing in the spreadsheet) starts at the Sydney-end of the run and calculates all successive droppers until the end anchor is reached (or some other aspect halts it).
- Suitable for either fixed-anchored or regulated OHW.
- Accurately model all loads in the bay, including the weight of each dropper and in-span feeder.
- It needed rail track levels, to accurately determine the bays of droppers, which is particularly important in those bays that are influenced by track vertical curves. Ideally with this way no adjustments should be necessary.
- Able to calculate single catenary / single contact, single catenary / twin contact and twin catenary / twin contact OHW systems. Ultimately include the Compound OHW system as well.
- Take into account bays that may have additional load points, such as the weight of a section insulator at a certain distance into the bay.
- Twin contacts could be supported either by single droppers for each contact, or using the "delrin bar" droppers to support twin wires spaced 50mm apart from single dropper to catenary.
- Cater for presagged, flat or hogged bays.
- Contact ramping down or up in a bay.
- Specially calculated droppers for overlap bays, where the dropper loadings aren't uniform throughout the bay due to the contact wire/s going out-of-running at one end of the bay.
- Pennant bays, where the dropper placement and lengths may be less important.
- Contact support loadings from previous bay and next bay taken into account for determining dropper lengths in the current bay.
- Provide a suitable summary for ordering all *droppers* and *in-span feeders* in each bay of the wire run. To include the resulting dropper lengths and the specific dropper fittings that make them, and in-span feeders fitting numbers (lengths), along with the *placement* of all these within each bay of the wire run.

The resulting dropper program was much more comprehensive and accurate than other dropper programs, and mostly worked for the regulated and fixed-anchored OHW (but unfortunately time ran out for including the Compound OHW system).

DETACHED DROPPERS

Droppers are one of the items in the OHW system that seem to need relatively constant attention, because:

- They are one of the few things that move (due to contact uplift with passing pantographs) and can thus wear out,
- They are in close proximity with the train pantographs and can therefore be quite susceptible to damage, and
- There's just so many of them throughout the electrified network (numbering in the millions).

If a dropper fails by whatever mechanism, it normally shows up as a "detached dropper". See *Figure 91* for examples.

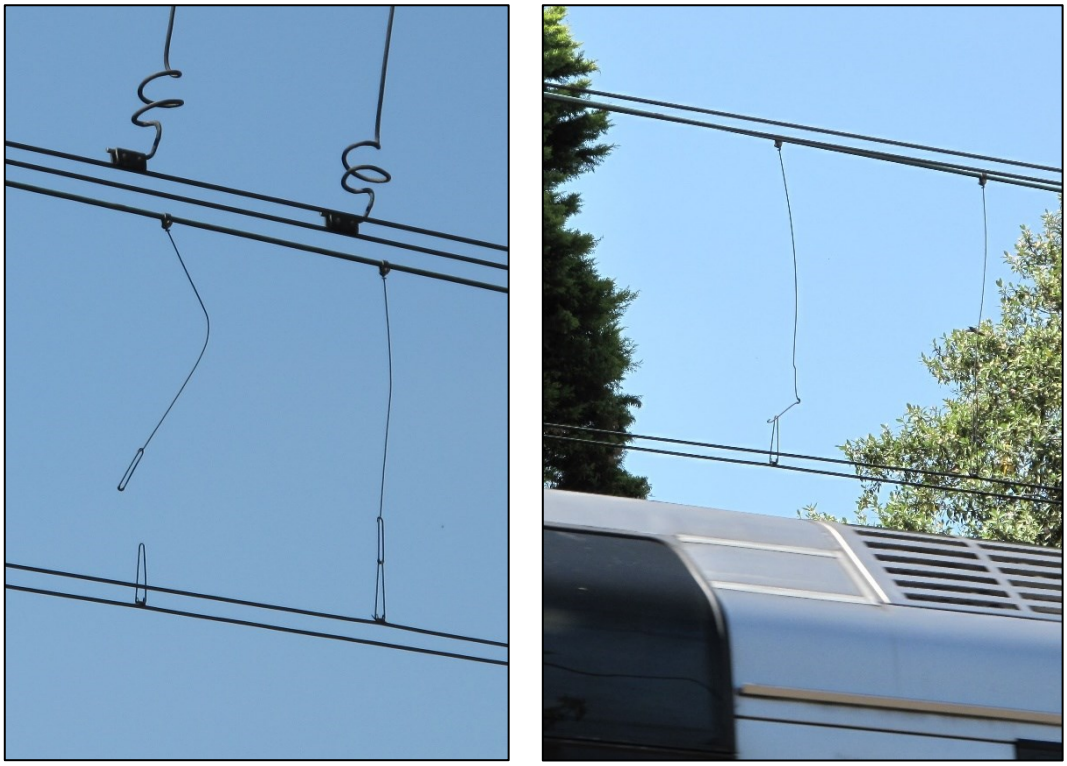


Figure 91 - Examples of detached Droppers

Fatigue is one culprit to the effective performance of droppers over the years. To combat fatigue, any parts that are cyclically stressed (by the constant passing of pantographs with their upward pressure) usually require some form of pin connection to allow free movement and rotation if required. This policy has worked well since the early days of Sydney's electrification.

In most bays, the *detachment* (failure) of any one dropper can be helped by the next dropper on each side. For example, in regulated OHW the spacing between droppers in a particular bay may be 7m, so if one dropper becomes detached the spacing becomes 14m until corrected. The adjacent droppers can support the additional contact weight, and even the additional contact sag, in what becomes double the "baylet" (for want of a better term), can be tolerated by trains (especially if the wire is regulated).

Having 2 or more *successive* droppers detached is more likely a real problem, for obvious reasons.

Fixed-anchored OHW is particularly vulnerable to nasty effects if one or more adjacent droppers become detached and no longer support the contact wire. Possibly the worst case is when the contact wire is hot.

Example of Detached Droppers in Tunnel

Refer to *Figure 92* for this example of a somewhat typical fixed-anchored OHW situation inside a tunnel, with an already low standard contact height of 4.75m (but typical of tunnels).

A 193mm² contact wire with a fixed-anchored design tension of 13.35kN at 21°C plummets to 1.87kN at 55°C. (Refer to *Table 17*.) At this reduced tension, the contact wire sag between droppers is *24mm* (with droppers spaced at 4.57m apart).

If one dropper becomes detached (which is unlikely within the confines of a tunnel), then the span between supporting droppers becomes 9.14m and the contact sag in this longer unsupported distance increases to *94mm*.

In the *extremely unlikely case* of 2 *consecutive droppers* becoming detached, then the span becomes 13.7m and the corresponding sag is a huge *212mm* when *hot*!

In the open route with a standard contact height of 5m, losing 212mm at mid-bay is not likely to cause clearance problems to passing trains (although it may prompt drivers to slow down due to arcing, etc.).

However, the OHW inside tunnels is often designed so that the contact height at mid-bay when hot is just above its minimum, i.e. 4.57m @ 55°C (albeit with allowances for other tolerances, etc. taken into account). This is what's shown in the top diagram in *Figure 92* with the full droppering, and this is quite okay.

If a single detached dropper occurs at mid-bay, then the 4.57m minimum height becomes 4.50m, which is only 80mm above the top of train – probably still okay. Middle diagram.

However, if there are *2 consecutive detached droppers*, and this occurs *towards the middle of the bay*, then the contact height becomes about 4.38m, which is 40mm lower than the top of a train (4.42m). In which case, the contact wire will rest on the train roof. See bottom diagram of *Figure 92*.

Of course, a contact wire resting on top of a train means the train has no electric power and it won't be going anywhere for a while! Note that the OHW should then begin to cool, tensions increase and, provided the contact wire hasn't welded to the train roof, the contact wire may again lift above the top of train, whence power could (in theory) be reapplied.

Anyway, this is why it's so important to keep tabs on the condition of fixed-anchored droppers, and especially inside tunnels or other areas that already have reduced contact heights. While it might seem okay to ignore one detached dropper for a while, the real risk is that its neighbour does the same, in which case it will more likely stop trains – in a tunnel (or approaching or under a low overline bridge). In the open, this is again not likely to be a problem – it's the tunnels that are a concern here.

It's also important that the original design and installation of the OHW was carried out correctly, because there's little vertical room for error here.

Notes:

- If the detached dropper is located near one of the supports instead of at mid-bay, the lowered contact height will not be as dramatic (catenary sag is less), which is good.
- This example is not intended to dismiss the fixed-anchored OHW system as being unsuitable for use inside tunnels. Indeed, *time has proven fixed-anchored OHW to be extremely reliable inside tunnels*, provided it is suitably designed and maintained (which is needed anyway with anything mechanical).

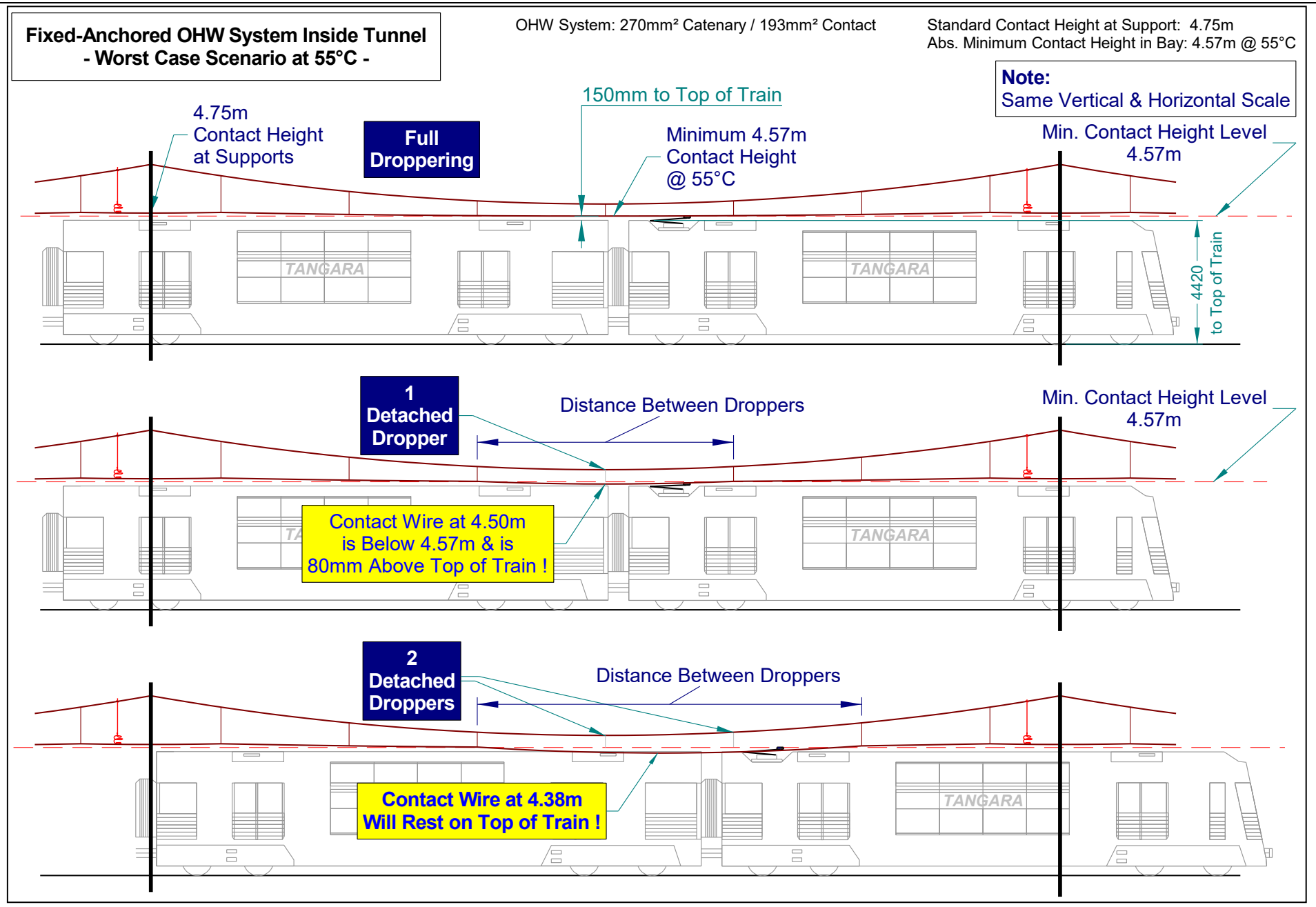


Figure 92 - Possible effect of 1 or 2 detached Droppers on Train Operations

Wynyard, 2016

I understand a situation similar to the above happened at the end of 2016 at Wynyard where, because of the extremely tight space inside these tunnels, it only took one detached dropper, on an extremely hot day, to allow the contact wire to touch the roof of trains, and cause mayhem.

The detached dropper was in amongst already badly spaced droppers supporting a contact wire going out-of-running to anchor, thus resulting in a large distance of unsupported contact wire just ready to sag when hot.

Apparently, there were several DCCB trips leading up to this event that gave a hint of what was to come, and it happened for the pm peak, resulting in the contact wire finally resting on top of a train, which then became stuck (no power). Passengers were not impressed as they eventually walked out from the tunnel (which was like an oven) to the station platform.

Sometimes these situations happen because of a wrong belief that fixed-anchored OHW can be installed and behaves like regulated OHW. Unfortunately, the character of its behaviour is totally different and needs to be understood and treated as such.

In this situation, one additional dropper, installed in the right place, would likely have prevented the problem (at least hopefully until the next thorough inspection was carried out – and corrected?).

Note that having *regulated* OHW in the above situation gives far superior results, even though the dropper spacing is greater (about 7.5m for regulated OHW versus about 4.57m for F/A).

With the same OHW sizes as above, but now regulated, typically the contact sag between droppers becomes 7mm (not 24mm), and
with 1 dropper detached the sag is 26mm (not 94mm) and
with 2 droppers detached is 60mm (not 212mm).

But these are places where you may not be able to readily regulated the OHW, and the costs to do so may be prohibitive. Fixed-anchored OHW is normally quite suitable, but it needs to be correctly designed, installed and maintained.

Note that overhead conductor rail systems also have a place in these tight situations.

DRIFTED DROPPERS

If the dropper is no longer vertical, something has happened to cause the dropper to "drift". Refer to *Figure 93* which shows either the catenary drifting to the left or the contact drifting to the right.

In a regulated OHW system it is more than likely caused by the contact wire stretching. It is also possible an anchor has slipped allowing the wire to move.

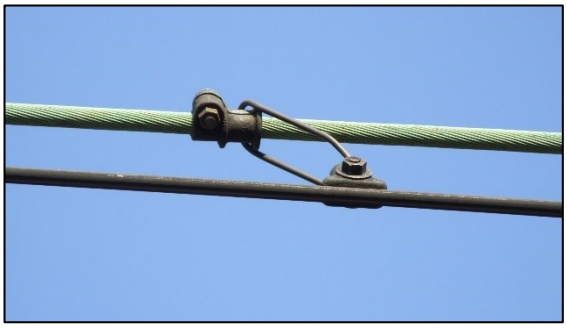


Figure 93 - Drifted Dropper

In any case, a drifted dropper can indicate something more sinister has happened either locally or even remote from this location, and it should be checked out as soon as possible.

If it's just one dropper that's affected, this can give a different clue compared to the situation of a series of droppers all shifted in the same direction.

Sometimes the contact clamp can be struck by a pantograph and cause it to move.

In any case, the unusual situation should be quickly corrected so that it doesn't prompt future questions and waste time, and so it can again be used to detect some abnormality of the wiring in the future.

Note that the new style of droppers mostly doesn't require a catenary clamp, which will make it difficult to detect any relative wire drift in this regard (the dropper will remain vertical).

LOCATION OF DROPPERS

There are some things to be appreciated with the actual location of droppers in a bay, particularly the first and last droppers in the bay.

It might seem natural and okay to install a dropper at the catenary support location (which defines the start or end of a bay), but this is not a good place for a dropper to support an in-running contact wire! Why?

First & Last Droppers in a Bay

An in-running contact wire is never supported by a dropper at the catenary support location. I understand this is mainly for the reason that the dropper could eventually fatigue. The reasoning follows.

In a bay of OHW, the catenary wire sags under its own weight plus the weight of the contact wire, in-span feeders and other items being supported.

The uplift force from a passing pantograph will lift the contact wire as it passes through a bay of OHW, and so the localised weight of the contact wire, as well as portions of the droppers and in-span feeders, are temporarily supported by the pantograph pushing up (and not the catenary).

Thus, the catenary wire, having less weight when pantographs are in the vicinity, tends to lift in sympathy with the contact wire.

With a pantograph at mid-bay, the amount the catenary wants to lift can be more than the contact lift, in which case the droppers remain in tension (i.e. they are still supporting some contact weight).

However, at the catenary support location the catenary essentially cannot lift by much (if at all.)

If a dropper was installed at this catenary support location, as uplifted pantographs pass through, they would lift the contact and tend to suddenly drop it as the pan quickly passes through. So, the dropper's lower loop and upper loop would be momentarily unloaded (causing the 2 loops to separate by a small vertical distance), then suddenly loaded again as the pantograph quickly passes.

Although this might seem harmless and almost trivial, the countless millions of pantograph passages would eventually lead to localised wear and/or fatigue of the dropper arrangement if installed at this catenary support location.

A pull-off arm is usually located at this support point also, placing about half its significant weight onto the contact wire, which would exacerbate the dropper unloading / sudden loading situation.

Also, should these droppers become disconnected from the contact wire, they can be struck by passing pantographs and may become entangled around the OHW support & registration arrangement there, causing a sustained electrical fault on the system, and stopping trains.

Placing the first dropper a few metres away from the catenary support location helps provide a certain "cushioning" effect (or "compliance") to the unloading and loading of the dropper as a pantograph passes, and this is good. From the pantograph's perspective, it would also see a

more uniform contact wire weight through this area – again a good thing – leading to a minimum of disturbance to the contact wire, which successive pantographs of the same train need to then negotiate.

Somewhat related to the above, it's probably worth noting that, in the old fixed-anchored OHW system, the dropper lower loop came in 3 lengths – 150mm, 200mm and 300mm. The last dropper before and the first dropper after the catenary suspension point used to be fitted with longer 300mm loop in the droppers, in order to accommodate the expected greater contact uplift experienced near suspension points. (The longer loops were necessary because of the poor performance / extremely low tension with hot temperature in a fixed-anchored OHW system, and combined with the fairly localised upward pantograph force from multiple-header locomotives with all pantographs up – a horrible situation for the OHW to cope with.)

Droppers at Mid-Bay Pull-Off Locations

Unlike at a catenary support location (described above), it does not matter if a mid-bay pull-off location coincides with a dropper location.

This is because at mid-bay, a passing pantograph will push the contact wire up (due to the upward pantograph pressure), which unloads some of the contact wire weight from the catenary, and the now unloaded catenary wire tends to rise because it is not supporting as much weight. The rising catenary then tends to lift the contact wire with it, and this results in a certain amount of "compliance" or softness in the OHW/pantograph interface.

So, no problems with dropper locations here.

ADJUSTMENTS

The length of each dropper in each bay of a wire run, is intended to be calculated and manufactured to a specific length, ready for installation. This is good in theory, however sometimes there's a need for some small adjustment in length due to unforeseen or site-specific circumstances. This is especially true if the installed dropper rattles (a "rattler") which means it's not supporting the contact wire and needs some adjustment (shortening) to pick up some contact wire weight (otherwise it might wear prematurely).

When installers are confident that the droppers will be the correct length and not need adjustments, then the 2-piece droppers can be manufactured with the upper loop tied off at the catenary clamp ready for installation.

However, if there is any uncertainty regarding possible need for adjustments to length, then sometimes the top part of the upper loop can be ordered as a straight piece of dropper wire that can be tied off in the field to the needed length. (The upper loops can be supplied in several standard "straight" lengths.) It may be possible to readjust this tied-off length a second time, but beyond that, this undoing and redoing can cause the wire to be weakened such that it can eventually fatigue at the tie-off point to catenary clamp. This fatigue failure can happen some time later, so this method needs to be used with care. (It can also waste some of the unused copper.)

When dropper installation work has been completed for a particular run, all droppers should be properly tied off. But sometimes people forget to finish this and move onto another project, and it just leaves the OHW looking unfinished (awaiting further changes?). So, when the operation of the new or altered OHW is deemed satisfactory, there should be a follow-up activity to tie off all droppers. After all, the droppers were not designed to be in this untied state.

ARCING WEAR ON DROPPERS

Without any insulation in the dropper arrangements, the older droppers used to pass small amounts of current between catenary and contact wires, even with in-span feeders nearby.

Electrical current will take any path available to it, and the significantly higher currents supplying trains these days leads to higher levels in these alternate current paths.

If there was any amount of looseness in the various dropper connections, these are points that could spark if current is being passed at the time they're moving about, e.g. the upper loop / lower loop connection. Refer to *Figure 94*. Such sparking is "micro-arcing".

Over time, the micro-arcing will eventually wear or erode the connection – the stainless steel or copper or brass will eventually be significantly damaged in time (sometimes measured in years or decades).

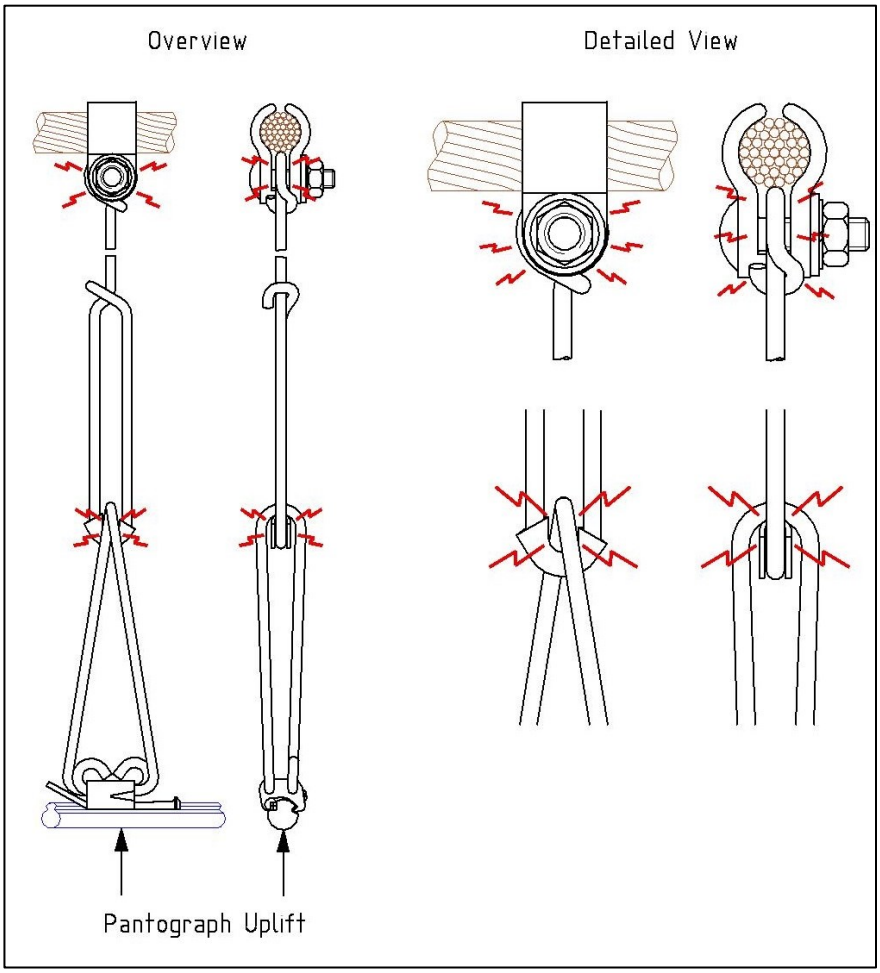


Figure 94 - Points of arcing in old Dropper arrangements

Refer to *Figure 95* for some examples of damage due to dropper wire micro-arcing.

The left-hand photo shows how a solid dropper wire (as used in *Figure 93*) can "saw" through the substantial thickness of a catenary saddle clamp fitting. This happens as the dropper moves up and down with pantographs passing (which occurs more with the reduced wire heights at overline bridges), with erosion due to micro-arcing as current is delivered to the pantograph.

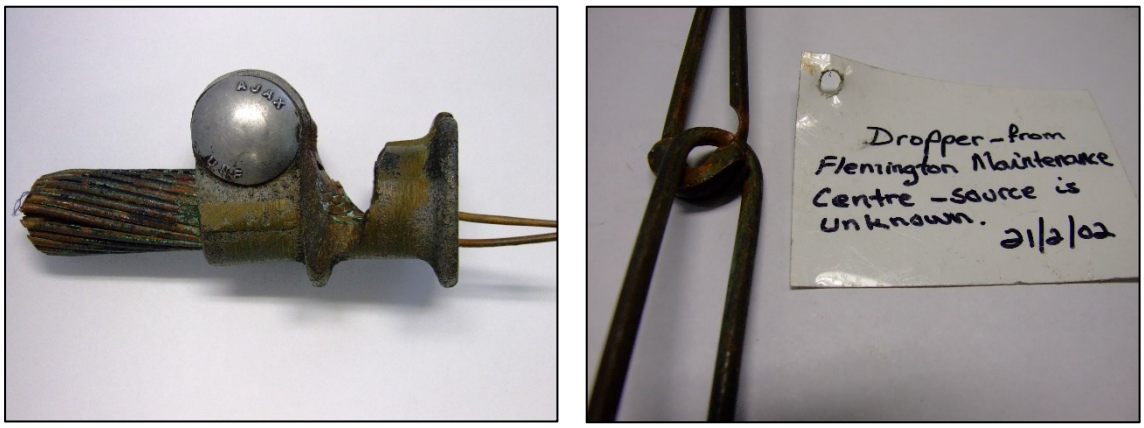


Figure 95 - Examples of damage caused by Dropper "micro-arcing"

The right-hand photo shows wear at the loose connection between the upper and lower loops, again aided by micro-arcing per *Figure 94*. This wear happens as a consequence of the multiple-millions of pantographs passing through each year, with each causing the wire to disconnect while a small portion of the train current is drawn through the dropper.

The introduction of plastic sleeves to the dropper wire in the early 2000s for old (a retro-fit item) and new dropper arrangements, will prevent such micro-arcing in future.

TWIN CONTACT DROPPER PROBLEMS

Even though twin contacts provide superior performance with pantograph interaction, current rating, etc., there are some things that are less than ideal, but are lived with.

Figure 96 - Dropper Pairs in Twin Contact OHW

Wear Pattern with 1m Dropper Spacing

Twin contact wires are normally spaced either 150mm apart or 50mm apart in each bay.

When they are 150mm apart, one contact wire is supported by its own independent set of droppers to the catenary wire, and the adjacent contact wire also has its own set of droppers but spaced 1,000mm further along, and again supported from the same catenary. (These dropper pairs are actually located ±500mm either side of the equivalent single contact dropper positions.) See *Figure 96* for an example.

Because the contact wire sags between droppers, and the dropper pairs are offset by 1,000mm with each other, this can lead to the one contact being slightly lower than the next, and a bit further on the reverse happening, and so on throughout the bay.

Over time, with millions of passing pantographs, this has the effect of uneven wear on each contact wire in a localised fashion throughout the bays.

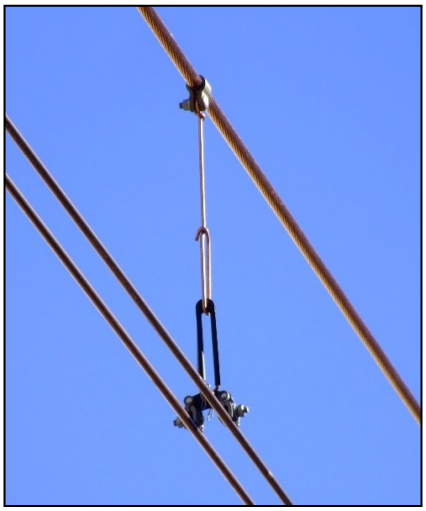


Figure 97 - Latest Delrin Bar Dropper arrangement

Contrast this with the *delrin bar* arrangement (*Figure 97*), which supports contact wires spaced 50mm apart and uses a single dropper to the catenary.

The delrin bar forces both contact wires to be in contact with the pantographs at all times right throughout the bay. It does this by rotating to an equilibrium position under the influence of the pantograph uplift force. So both wires share the uplift load and wear at the same rate.

This is one of the many reasons why I much prefer the delrin bar arrangement when twin contacts are used.

Superelevated Track

For simplicity of calculations, the various dropper programs that determine suitable dropper lengths result in twin contact wires being *level* with each other.

However, the height of each of the 2 contact wires should ideally be referenced to the *lateral slope* of the pantographs when on superelevated track. The incline of the track can make a big difference to the ideal contact levels especially with the larger 150mm contact separation.

If a bay has pairs of droppers spaced 1,000mm longitudinally apart, the end result can be that the pantograph tends to connect more with the relative lower of the 2 contact wires, which would be the one on the higher side of the inclined track, causing it to wear at a faster rate.

Example:

> If the track superelevation is 120mm (i.e. a tight track curve), the difference in contact height of the 2 contact wires at the same level is about 4mm for 50mm twin contact spacing, and 12mm for 150mm twin contact spacing.

Even though these small 4mm and 12mm distances seem trivial, they can have a big impact on the amount of wear on each wire over the long term.

So, contacts spaced 50mm apart can exhibit a small error in this regard, but the 150mm spaced contacts are 3 times as much.

This is one area that could be improved in future if separate droppers are employed for supporting twin contacts. (The delrin bar arrangement has so many other benefits, so I sometimes wonder why the single droppers are still used in this twin contact situation.)

This is probably one of the main reasons why having pairs of droppers spaced 1,000mm longitudinally apart is only suited to a regulated OHW system. The way the fixed-anchored contact tension plummets under hot conditions (e.g. 13kN @ 21°C down to 2kN at 55°C), would make these dropper pairs unworkable when hot. Again, the delrin bar arrangement has been used in this fixed-anchored situation to provide a superior solution.

OVERLAP DROPPERS

In an overlap bay, the in-running contact wire from one end of the bay begins to rise near mid-bay to become out-of-running as it heads to the other end of the overlap bay.

It is desirable to have the OOR contact wire rise as quickly as practical, mainly to get well clear of passing pantographs below – and especially to clear the bottom skirts of a pennant insulator if installed on this wire (see *Figure 154* later in document). But the rise of the contact wire is limited by its natural sag – it begins to rise slowly (following a length-squared law). E.g. it takes 10m to rise the initial 50mm, but only takes a further 4.5m to rise another 50mm, etc.

So, to get the maximum contact rise, ideally the contact wire shouldn't be supported by droppers between where it needs to start going out-of-running, and all the way to its OOR support location. This is what was done with regulated OHW, until only recently.

Refer to *Figure 98* which contrasts the droppering of regulated versus fixed-anchored OHW in an overlap bay.

Fixed-anchored contact wire requires droppers to uniformly support it throughout the overlap bay, as it would in any normal bay of OHW. This is because its slack tension at hot temperatures would otherwise cause the OOR contact wire to droop into the path of a train. See *Figure 99, Case (d)* – of course this situation is totally unacceptable.

In regulated OHW, the trick is to know how much to support the OOR contact wire (i.e. how much to load the droppers by lifting the contact wire a bit), and still have it rise out-of-running at a reasonable rate, to get its needed height at the OOR end of the bay, without getting loose droppers – "rattlers" as they're known (which may then wear out over time).

So, roughly half the bay has the catenary supporting the contact wire, but the remainder of the bay has no (or little) added contact wire load. The effect is a distorted catenary shape, which the dropper program needs to work out accurately, so as to determine precise dropper lengths.

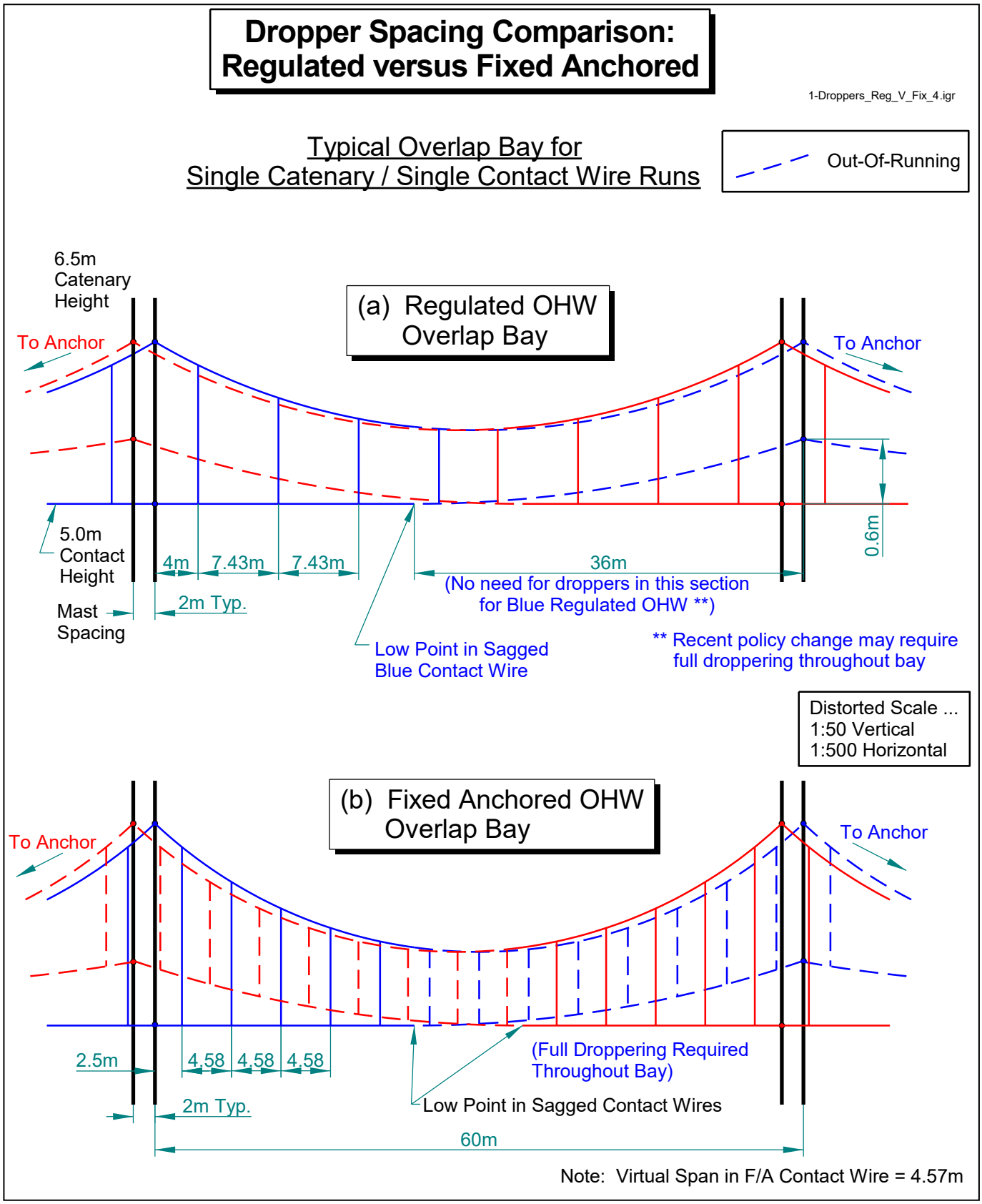


Figure 98 - Dropper spacing comparison – Regulated versus Fixed-Anchored

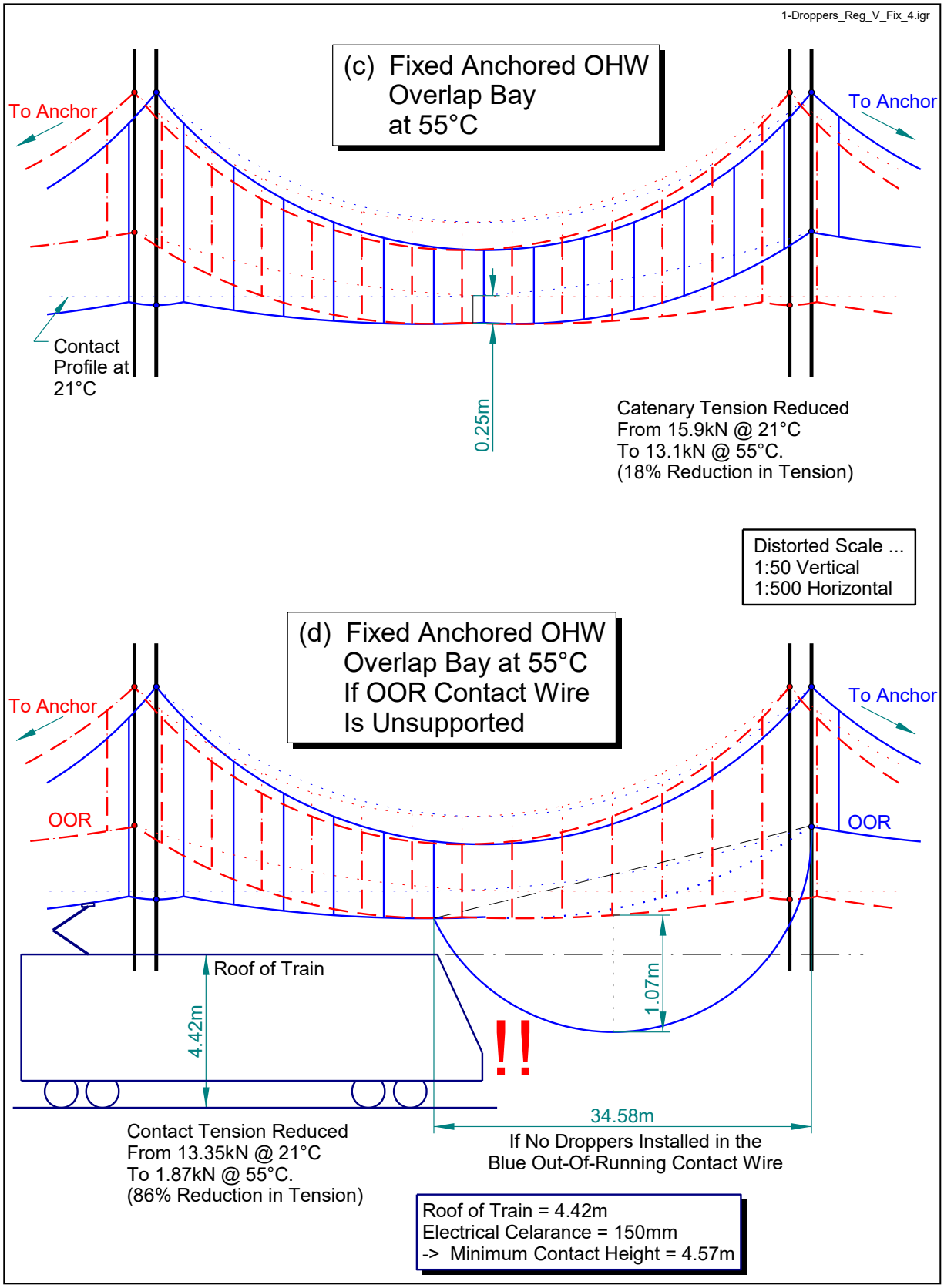

1-Droppers_Reg_V_Fix_4.igr
(c) Fixed Anchored OHW Overlap Bay at 55°C
To Anchor
To Anchor
Contact Profile at 21°C
0.25m
Catenary Tension Reduced From 15.9kN @ 21°C To 13.1kN @ 55°C. (18% Reduction in Tension)
Distorted Scale ... 1:50 Vertical 1:500 Horizontal
(d) Fixed Anchored OHW Overlap Bay at 55°C If OOR Contact Wire Is Unsupported
To Anchor
To Anchor
OOR
OOR
Roof of Train
4.42m
1.07m
!!
34.58m
Contact Tension Reduced From 13.35kN @ 21°C To 1.87kN @ 55°C. (86% Reduction in Tension)
If No Droppers Installed in the Blue Out-Of-Running Contact Wire
Roof of Train = 4.42m
Electrical Celarance = 150mm
-> Minimum Contact Height = 4.57m

Figure 99 - Droppering for Out-Of-Running Fixed-Anchored Contact Wire

3.1.3.6 Status (c. 2014)

For future work, the half-moon & shell type catenary fittings are being replaced by the 2 piece catenary clip.

Also, the new dropper arrangements as shown in *Figure 84* are to be used in future.

3.1.3.7 Reference

Old standard dropper arrangements:

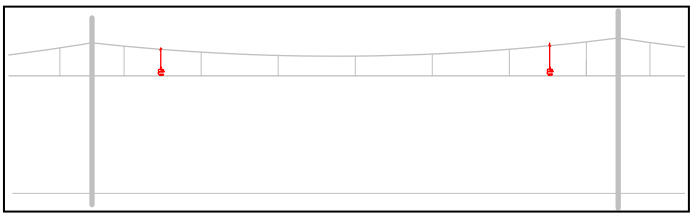
- Single Contact – see drawing D/80649 sheet 2.
- Twin contact – see drawing D/80589 sheets 1 & 2.
- Short dropper (twin contact) – see drawing D/80588.
- Restricted dropper (single contact) – see drawing E/73734.

New standard dropper arrangements (for all future work):

- See *Figure 84 - Mapping of all new styles of Droppers* for dropper standard arrangements and associated fitting numbers and drawing numbers.

Figure 100 - Droppers grouped & numbered for sequential installation into nominated Bays

3.1.4 In-span Feeders



3.1.4.1 Description

In-span feeders typically appear as "helical coils" in each bay of OHW between the catenary and contact wires. Older style in-span feeders take the shape of a "pig tail".

Compound OHW uses a special configuration that connects the catenary to auxiliary catenary then to contact.

Refer to *Figure 101* for the various types of in-span feeders.

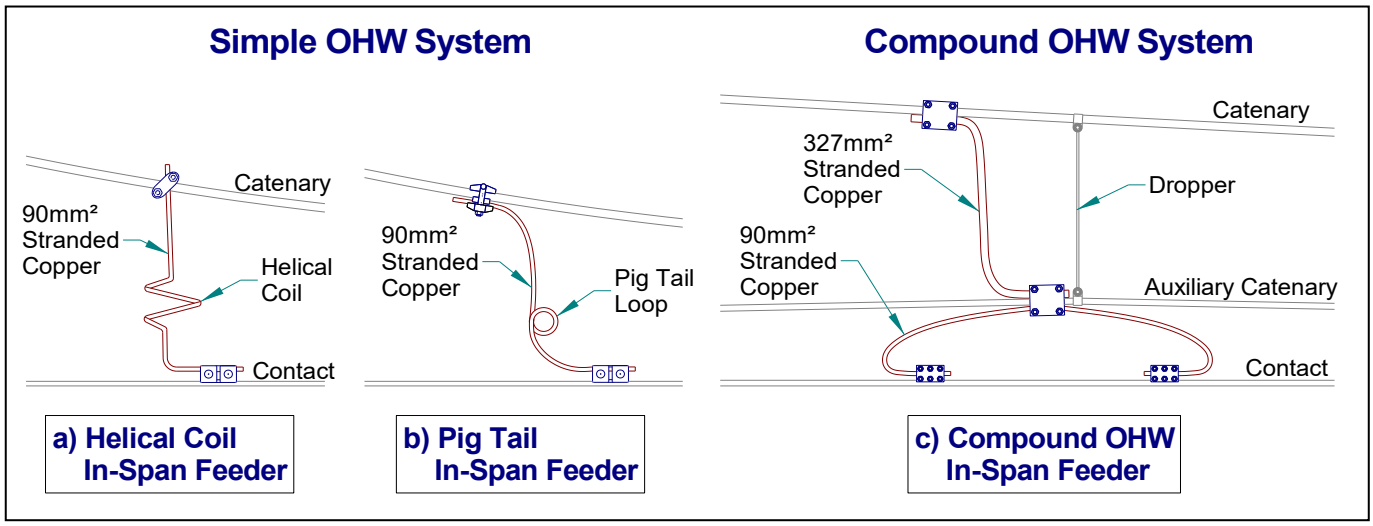


Figure 101 - In-Span Feeder Types

3.1.4.2 Function

In-span feeders provide the means of transferring heavy current from the catenary to the contact wire/s, and vice-versa, thus reducing the tendency for current to feed through the droppers. (Droppers are not designed to feed current, so this must be avoided.)

3.1.4.3 Typical Components

In-span feeders consist of a length of multi-stranded copper wire, a catenary clamp and contact clamp to make the top and bottom connections.

3.1.4.4 Configuration

In-span feeders are made from multi-stranded copper wire (typically 90mm², 91/1.12mm hard-drawn bare copper). This wire is stiff enough to keep its helical shape, but its coil shape is flexible enough to compress when required, e.g. as the pantographs lift the contact wire.

There are basically 2 types for the simple OHW system:

- ***Helical Coil*** – This is the current standard type in-span feeder, and has the greatest population in the OHW system by far. It has a "coil" shape between the catenary and contact wire connections. The coil shape is there to ensure that the in-span feeder can compress and expand vertically as the catenary and contact wires move relative to each other (particularly with pantograph uplift). This prevents fatiguing the feeder wire over time, and importantly, its presence does not present a "hard spot" to the pantograph. This

type of in-span feeder is preformed at the workshop and it comes in different standard lengths (generally in increments of 300mm). Refer to fittings 475/4 to 475-21.

- ***Pig Tail*** – An older type of in-span feeder was shaped like a pig's tail, but has been superseded many decades ago because of inherent fatigue problems in the feeder wire at the clamp attachments. Because of its simplicity, this type was normally formed on site.

In-span feeders for the compound OHW system (across the Blue Mountains) connect the catenary to the auxiliary catenary using 61/0.105" (~327mm²) "jumper" wire, then to the contact wire using 37/0.072" (~90mm²) copper in-span feeder wire.

I was told that, because the 327mm² wire was so large, it needed to be annealed before being bent into shape, and they did this by heating it to high temperatures. The bundle of strands for both the 327mm² and the 90mm² in-span feeder wires were each bound with a regularly-spaced single strand of copper wire, which is twisted at the ends to keep its circular form. This helped keep the feeder wire strands bundled together and not "birdcage", especially where the wires were bent to form the "U" shape. A close look at *Figure 106* will show this way of controlling the strands. I guess this was particularly important for the 327mm² wire since its annealed state had little strength to keep it in shape. (Note that the action of clamping to catenary and auxiliary catenary, locks the individual strands from moving which, provided the strands don't birdcage, causes the in-span feeder wire to become stiffer.)

An effective electrical connection of catenary clamp to the catenary wire, and the contact clamp to the contact wire, required that the copper of the catenary surface and contact wire notches be properly *cleaned* before installing the clamps, and the clamps to be *tightened* firmly. Large feeder clamps are used to ensure that adequate clamping pressure is applied at these connections.

These actions reduce the likelihood of a high resistance joint developing, with consequent burning/annealing/breaking of these main wires under high tension. (Any significant resistance at the clamp connection, when passing heavy currents, will heat the clamp and may ultimately cause annealing of the connected catenary or contact wires, with dire results.)

Figure 102 shows the current standard in-span feeder arrangement – fitting 475/2, which includes the contact feeder fitting 56/14. The catenary clamp is a "cross-clamp", meaning that both wires are installed at right angles to each other. On the other hand, the contact clamp is a "parallel clamp", which is the preferred way to help prevent the feeder wire from projecting below the bottom of the contact wire and clashing with a pantograph.

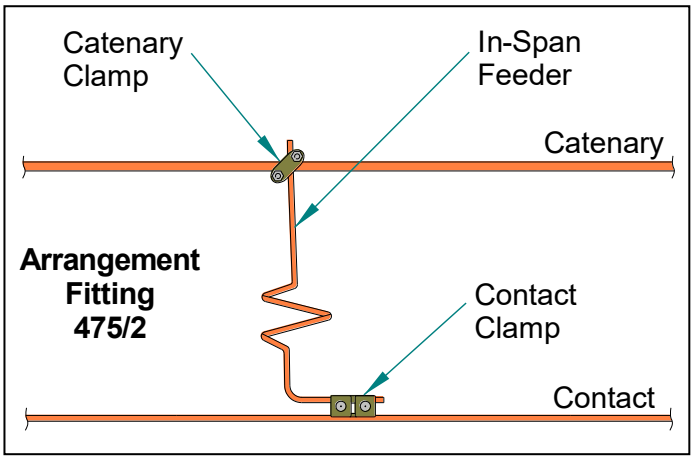


Figure 102 - Helical Coil In-Span Feeder

Figure 103 shows the typical configuration of in-span feeders for twin contacts.

They are normally spaced about 1m apart (in much the same manner as the individual droppers are typically spaced apart).

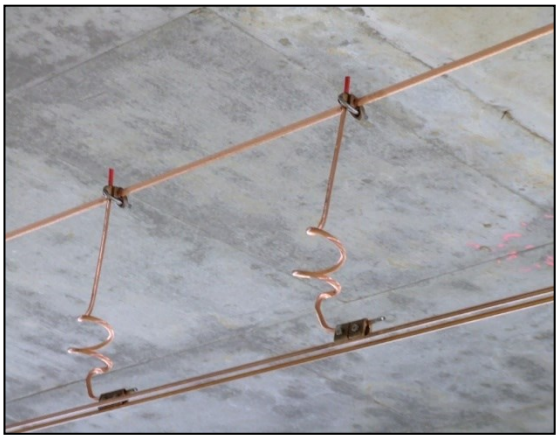


Figure 103 - Helical Coil In-Span Feeders on Twin Contact OHW

Figure 104 shows the configuration with twin catenary OHW.

Here, a pair of electricity industry line-tap fittings are used to interconnect the 2 independent in-span feeders, providing a neat outcome. In this situation it is unlikely that there would be much current flowing across the connection itself.

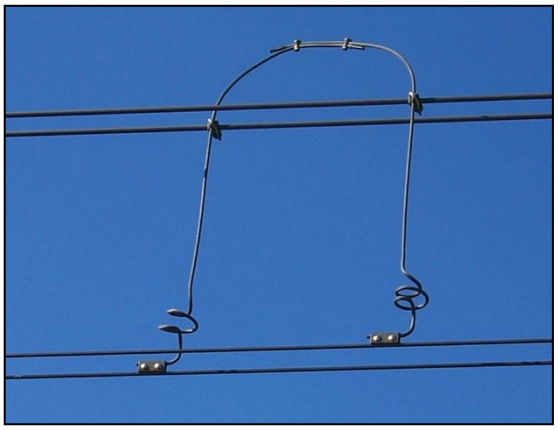


Figure 104 - In-Span Feeder connection with Twin Catenary OHW

Figure 105 shows a pig tail type inspan feeder, with its simply-formed single loop half way between catenary and contact connections.

I understand this arrangement often suffered from fatigue and subsequent stranding of the inspan feeder wire. This fatigue primarily occurred at the wire junction just outside the contact clamp and/or the catenary clamp.

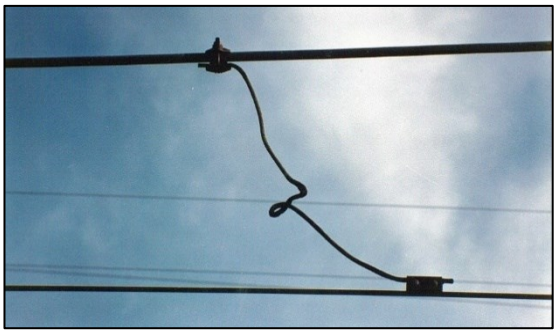


Figure 105 - Pig Tail type In-Span Feeder

Again, the slack contact tensions of a fixed-anchored system when hot, allowed significant contact uplift, particularly with the multiple closely-spaced pantographs of each passing freight train (when they used to run around the system). This action would have caused a fair bit of relative movement between catenary and contact wires, with the in-span feeder having to distort its shape accordingly in the process. Considering the huge number of pantograph passages each day, and for years on end, it is little wonder that fatigue eventually happened.

Note that a regulated OHW system would be much less likely to cause this fatigue because of the greatly reduced amount of uplift, but this older style of in-span feeder is now taboo.

The in-span feeder for the compound OHW system is shown in *Figure 106*. Its more complicated arrangement comes from the fact that there's an intermediate auxiliary catenary wire located between catenary and contact wires, and the in-span feeder has to make reliable connections to all 3 conductors.

In this situation, most relative contact uplift with passing pantographs happens between the contact wire and the auxiliary catenary wire, with very little occurring between auxiliary catenary and catenary wires. So, a single wire passes from contact clamp to auxiliary catenary clamp and back down to another contact wire connection. These 2 connections to the contact wire provide a solid low-resistance electrical connection to this important wire, offering some redundancy. I'm not aware of any fatigue problems with this arrangement.

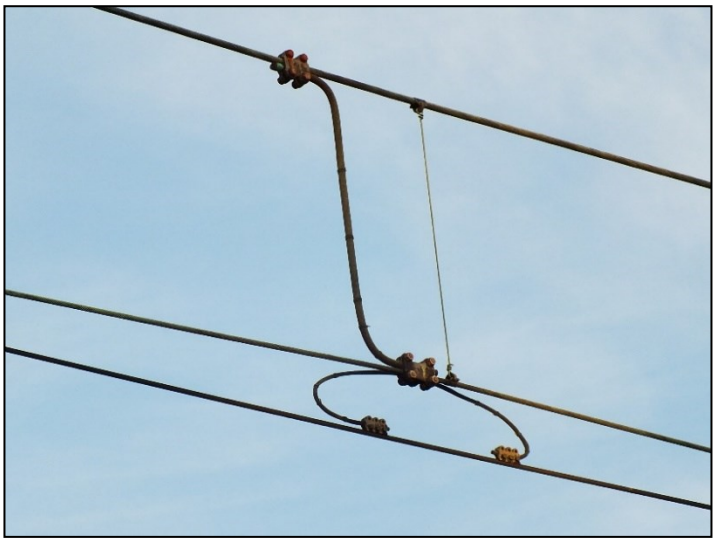


Figure 106 - In-Span Feeder in Compound OHW

A catenary to auxiliary catenary dropper (shown) is located next to the in-span feeder to allow the in-span feeder to hold its shape and just do its work.

The standard in-span feeder has a right-angle elbow bend at the bottom connection to the contact wire. It is important that this bend be installed such that if it becomes detached from the contact clamp, passing pantographs are less likely to snag and stretch the coil. If this were to happen, then its projection below the contact wire level would likely cause it to be struck by all passing pantographs and result in service interruptions. See *Figure 107* showing one such example that was snagged by one or more pantographs – not a pretty sight. An intact one is located next to it.

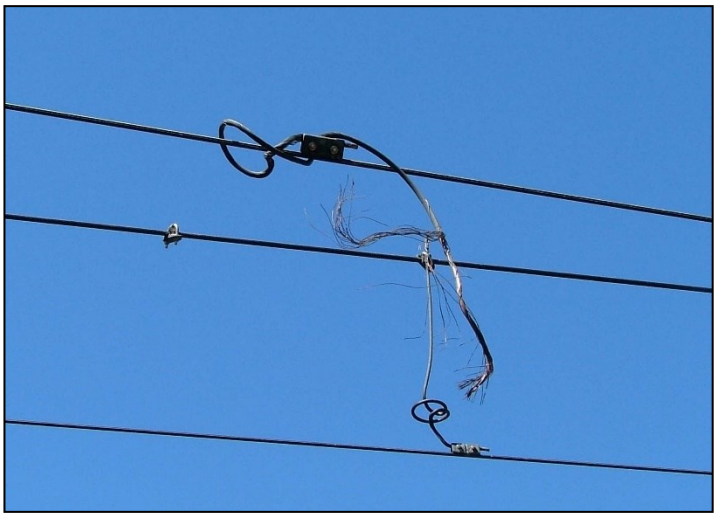


Figure 107 - Damaged In-Span Feeder

If this elbow is facing the opposite (correct) direction and becomes detached, it can be brushed aside by passing pantographs instead of catching (but only for slower train speeds). Then hopefully it would be noted and fixed as soon as possible.

Note that the intact in-span feeder in this figure would be suitable for trains travelling from left to right. All good in theory …

3.1.4.5 Design Notes

NUMBER OF IN-SPAN FEEDERS IN A BAY

Single contact OHW in short bays will have 1 or 2 in-span feeders, while long bays may have up to 4 in-span feeders in each bay. Double these numbers for twin contact systems (1 in-span feeder needed per contact wire).

It is critical that a *sufficient number* of in-span feeders are installed in each bay so as to reduce, to an absolute minimum, the level of current feeding through the multitude of droppers, which could otherwise arc and burn and thus wear prematurely. Note however that recent attempts to insulate all droppers will force all current between catenary and contact wires to flow only through these in-span feeders, making them work harder, thus the critical need for many in-span feeders in each bay.

Various drawings exist that show the required number and placement of in-span feeders, e.g. A3/89272 sheets 1 to 4 (EL0003482, EL0007762, EL0007802 & EL0011739).

LOCATION OF IN-SPAN FEEDERS

The correct placement of the in-span feeders in each bay is shown in the above drawings.

IMPORTANCE OF GOOD ELECTRICAL CONNECTIONS

With the introduction of insulation sleeves into the newer droppers since early 2000, and the retro-fit to older droppers, all electrical current from catenary to contact wires must pass through the in-span feeders as intended. Even though it was undesirable to have current feeding through the older droppers (because of arcing wear at the various loose connection points on the droppers), some current ended up passing through them which, considering their far greater numbers distributed within each bay, actually helped reduce the current burden on the in-span feeders.

Also, the OHW system is expected to deliver a far greater amount of energy to the trains now, and exacerbated by the regenerative braking available on more trains than ever before.

So, there were justifiable concerns with the introduction of insulation in droppers, that this action might result in the in-span feeders then becoming a problem due to any high resistance joints that may have been previously covered up by the droppers helping to feed current.

These days it is essential that all in-span feeders are properly prepared for installation, and that includes cleaning both the clamp connecting surfaces and the copper wires at the clamping points, and also that the correct torque is applied to all fasteners.

Importantly, as part of any installation of dropper insulation, a check should be performed to ensure that each bay has the required number of in-span feeders for the bay length, to current standards.

3.1.4.6 Status (c. 2014)

- Many years ago *Pig Tail* type in-span feeders were to be replaced with the *Helical Coil* type.

3.1.4.7 Reference

- Standard arrangement is shown on drawing D/88173, sheets 1 & 2.
- Typical number of in-span feeders per bay is shown on drawing D/85289 sheets 1, 2 & 3.
- Typical in-span feeders at feeding loops are shown on drawing D/82699 sheet 3.

3.1.5 Knuckles

3.1.5.1 Description

Knuckles are devices mostly made from steel or some insulation material, that mechanically connect a catenary to a catenary, or a contact to a contact, at about the same level.

This connection is normally made where the 2 wires come relatively close to each other, typically about 50mm or so, but in rare instances, over 1,000mm.

The knuckle offset position (stagger) relative to track centreline is usually quite important. Its position is sometimes controlled by a nearby arm, or it can result from being in equilibrium (i.e. balanced radial loads on each wire) if located away from any such solid restraint.

3.1.5.2 Function

Knuckles fix the placement of 2 adjacent OHW conductors, i.e. they set up an appropriate OHW geometry or alignment, typically to service crossovers, turnouts, etc.

Catenary knuckles provide mechanical constraint of one catenary wire relative to another. This may or may not include some insulation element suitable for 1500V isolation, depending on whether the adjacent wire is at a different electrical section or the same section (respectively).

As with catenary knuckles, the *contact knuckles* provide for this mechanical connection (with or without electrical isolation), but they also play an important part in controlling any passing pantographs, and they need to provide for a relatively smooth path in the process.

Sometimes the knuckle simply holds the 2 wires at a certain spacing, resulting in no or very little tension load in the knuckle. At the other extreme, if each wire dramatically changes direction at the knuckle, there can be enormous conductor radial loads from each wire, that the knuckle must then cope with. Indeed, quite often it takes 3 or 4 such knuckles, located in close proximity, to share the very high radial loads (so as to not overload each).

3.1.5.3 Typical Components

These include clamps that connect to the wire, and normally include some form of steel plate or insulated member (if electrical isolation is required), that can handle the types of mechanical (radial) loads imposed on the arrangement.

In the early days, and until only a few decades ago, the insulation medium was permali beam. But cycloaliphatic resin insulators are now called upon because of their immense strength and other benefits in this situation.

3.1.5.4 Configuration

A number of types of knuckles exist, as described below:

- Fixed Knuckle
- Sliding Knuckle
- Crossing Knuckle
- Insulated Knuckle

FIXED KNUCKLE

In fixed-anchored OHW, "fixed knuckles" can be used to set up appropriate OHW geometry. Also, if 2 catenaries come close together, it is generally wise to knuckle them together so as to avoid possible mechanical wear (with relative wire movement) and arcing damage (as current could possibly feed from one wire to the other when they touch).

See *Figure 108* for just a few of the newer types available. These can be used in regulated OHW because the standard contact swivel clamp can rotate to accommodate any differential longitudinal wire movement.

Some contact knuckles are designed for installation at or near where the contact wires cross – one on top of the other. These are limited to use in a fixed-anchored system where there is no relative longitudinal wire movement.

Other contact fixed knuckles generally connect two non-crossing contact wires together at approximately the same height, including those in *Figure 108*. These are suitable in both fixed-anchored and regulated OHW systems.

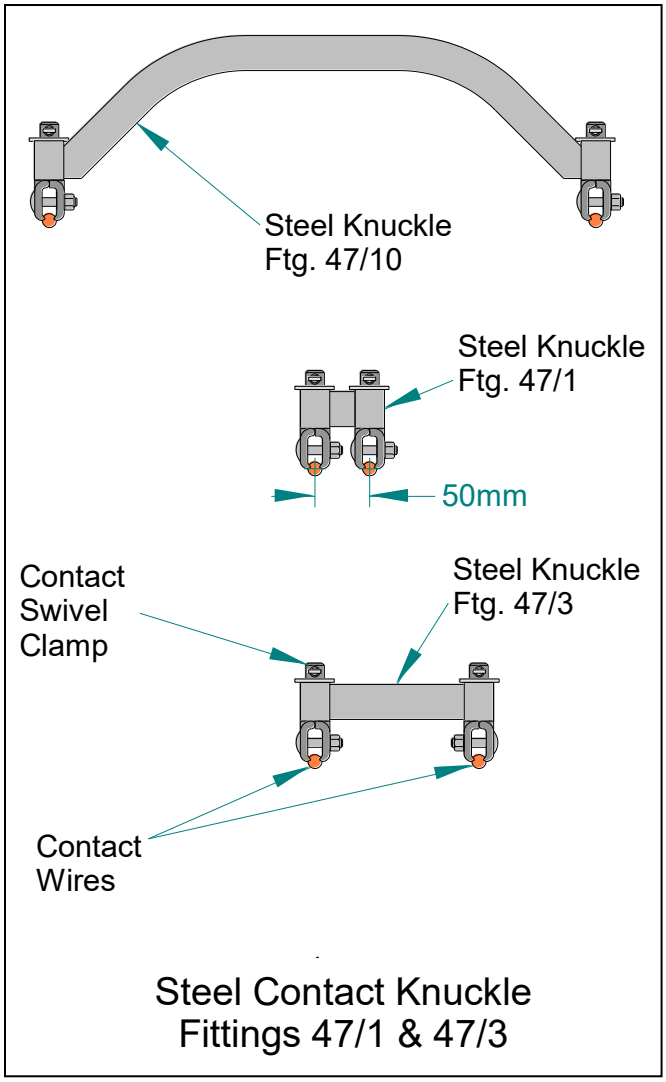


Figure 108 - Fixed Steel Knuckle arrangement

These contact knuckles are made in different lengths to suit the OHW geometry required at a particular location.

Figure 109 shows 2 instances of an older variety of steel knuckle installed at a crossover, along with 2 contact feeder jumpers. The swivel contact clamps used a ball & socket arrangement which are no longer used (I'm not sure of the reason why – maybe because of some hidden failure mode).

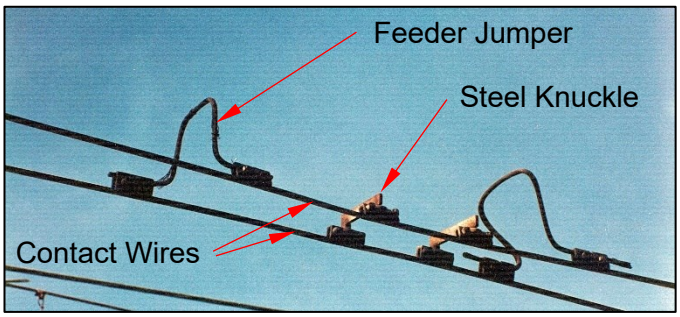


Figure 109 - Contact Steel Knuckle installed at a Crossover

The feeder jumpers are installed on the outside of the pair of knuckles, to try to pass all current flowing from contact wire to adjacent contact wire and deviate it away from the steel knuckles (which tend not to tolerate passing current in the long term).

Catenary fixed knuckles often include a U-bolt clamp that clamps around one catenary wire and the same for the other wire, and incorporate a flat steel bar which mechanically connects two catenaries together, sometimes with considerable tension.

Fixed-anchored catenaries that cross close to each other, are normally tied together with a U-bolt clamp, as shown at the top of *Figure 110*. This connection forces both wires to move together and not cause any abrasion of catenary strands. (More details of the clamps are in *Section 5.1.16.3*.)

In situations where a steel catenary wire crossed a copper catenary wire in close proximity, a fibreglass insulating sleeve was placed on the copper catenary, and the two catenaries were connected together using a U-bolt clamp. This insulation was only suitable for a low potential difference and was incorporated in order to prevent the detrimental effects of current feeding at the connection, especially since the catenaries are different metals (copper and steel).

Figure 110 - Catenaries knuckled

Fixed knuckles are not normally used in regulated OHW. If used, they need to be carefully designed and installed, because these OHW conductors move longitudinally with temperature. (A 1,000m length of regulated copper conductor moves along about 500mm with a temperature change of 30C°.) The exception is if there is *limited relative movement* between the wires, e.g. the 2 wires move in the same direction and at a similar rate. This typically requires the fixed anchors of the 2 runs to be located somewhat near each other.

In the long term, knuckle wear and wire fatigue are the enemies here.

SLIDING KNUCKLE

This type of knuckle is commonly used in regulated OHW contact wire, where one *contact wire* crosses immediately above another, and the wires need to independently be allowed to move longitudinally with temperature.

The sliding knuckle captures and restricts the upward relative movement of the upper contact wire. This is important in the situation where a pantograph is traversing the crossover and coming into the main line. In this situation the sliding knuckle forces the main line contact wire up in sympathy with any uplifted movement of the crossover contact wire, thus ensuring the main line contact wire slides up the horn of the pantograph and onto its top carbon strips. See *Figure 111* for an instance with single contact crossover wire coming into a twin contact main line OHW.

Figure 111 - Sliding Knuckles on Twin Contacts for Single Contact Crossover run

Figure 112 is the standard arrangement drawing for the sliding knuckle arrangement.

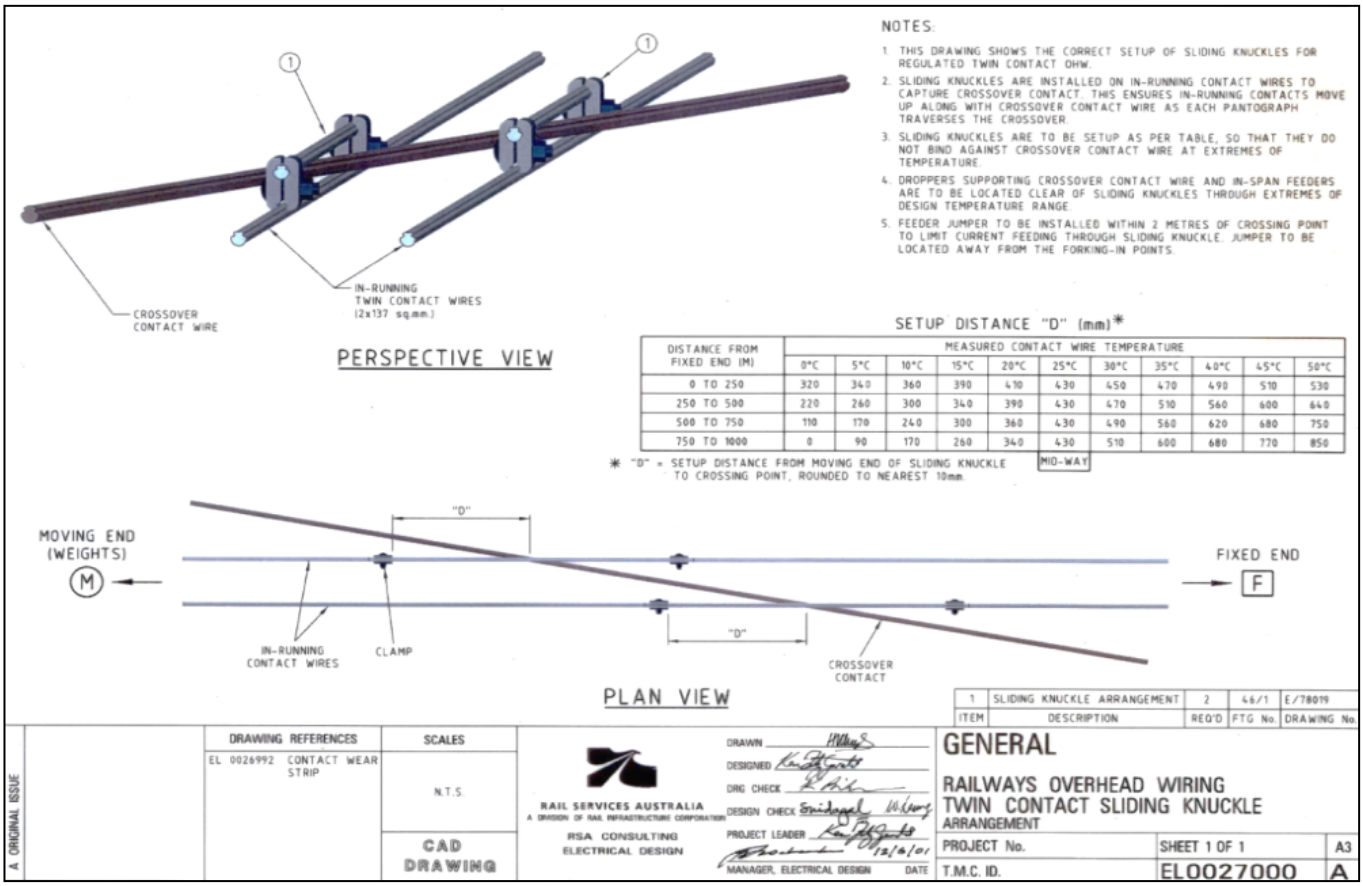

NOTES:
1. THIS DRAWING SHOWS THE CORRECT SETUP OF SLIDING KNUCKLES FOR REGULATED TWIN CONTACT OHW.
2. SLIDING KNUCKLES ARE INSTALLED ON IN-RUNNING CONTACT WIRES TO CAPTURE CROSSOVER CONTACT. THIS ENSURES IN-RUNNING CONTACTS MOVE UP ALONG WITH CROSSOVER CONTACT WIRE AS EACH PANTOGRAPH TRAVERSES THE CROSSOVER.
3. SLIDING KNUCKLES ARE TO BE SETUP AS PER TABLE, SO THAT THEY DO NOT BIND AGAINST CROSSOVER CONTACT WIRE AT EXTREMES OF TEMPERATURE.
4. DROPPERS SUPPORTING CROSSOVER CONTACT WIRE AND IN-SPAN FEEDERS ARE TO BE LOCATED CLEAR OF SLIDING KNUCKLES THROUGH EXTREMES OF DESIGN TEMPERATURE RANGE.
5. FEEDER JUMPER TO BE INSTALLED WITHIN 2 METRES OF CROSSING POINT TO LIMIT CURRENT FEEDING THROUGH SLIDING KNUCKLE. JUMPER TO BE LOCATED AWAY FROM THE FORKING-IN POINTS.
CROSSOVER CONTACT WIRE
IN-RUNNING TWIN CONTACT WIRES (2x137 sq.mm.)
PERSPECTIVE VIEW
SETUP DISTANCE "D" (mm)*
DISTANCE FROM FIXED END (M)
MEASURED CONTACT WIRE TEMPERATURE
0°C 5°C 10°C 15°C 20°C 25°C 30°C 35°C 40°C 45°C 50°C
0 TO 250 320 340 360 390 410 430 450 470 490 510 530
250 TO 500 220 260 300 340 390 430 470 510 560 600 640
500 TO 750 110 170 240 300 360 430 490 560 620 680 750
750 TO 1000 0 90 170 260 340 430 510 600 680 770 850
MID-WAY
* "D" = SETUP DISTANCE FROM MOVING END OF SLIDING KNUCKLE TO CROSSING POINT, ROUNDED TO NEAREST 10mm.
MOVING END (WEIGHTS)
M
"D"
FIXED END
F
IN-RUNNING CONTACT WIRES
CLAMP
"D"
CROSSOVER CONTACT
PLAN VIEW
1 SLIDING KNUCKLE ARRANGEMENT 2 46/1 E/78019
ITEM DESCRIPTION REQ'D FTG No. DRAWING No.
A ORIGINAL ISSUE
DRAWING REFERENCES
EL 0026992 CONTACT WEAR STRIP
SCALES
N.T.S.
CAD DRAWING
RAIL SERVICES AUSTRALIA
A DIVISION OF RAIL INFRASTRUCTURE CORPORATION
RSA CONSULTING ELECTRICAL DESIGN
DRAWN
DESIGNED
DRG CHECK
DESIGN CHECK
PROJECT LEADER
MANAGER, ELECTRICAL DESIGN
DATE
12/8/01
GENERAL
RAILWAYS OVERHEAD WIRING
TWIN CONTACT SLIDING KNUCKLE
ARRANGEMENT
PROJECT No.
SHEET 1 OF 1
A3
T.M.C. ID.
EL0027000
A

Figure 112 - Sliding Knuckle arrangement drawing

Where regulated *catenaries* are located close together, a physical gap needs to be maintained, and if there is any possibility of touching, a feeding loop will need to be installed nearby to prevent arcing due to intermittent current feeding when they touch.

CROSSING KNUCKLE

This type of knuckle is used in crossovers with fixed-anchored OHW. The crossover contact wire passes over the main line contact wire by about 40mm. See *Figure 113*.

Obviously, this arrangement won't tolerate any relative longitudinal wire movement, so is unsuitable for regulated OHW.

Figure 113 - Two views of a Contact Crossing Knuckle (steel)

INSULATED KNUCKLE

This type of knuckle is used where it is necessary to restrict the lateral movement of catenaries or contacts when in close proximity, while maintaining their electrical independence.

At Overlaps

Insulated knuckles are often used in fixed-anchored overlaps, to force the contact (and catenary) wires to remain parallel to each other throughout the overlap bay, even under hot (low tension) and windy conditions. (The extremely low contact tension when hot is the main reason for their use.)

The insulator typically used is a *permali beam* which is a specially manufactured laminated timber.

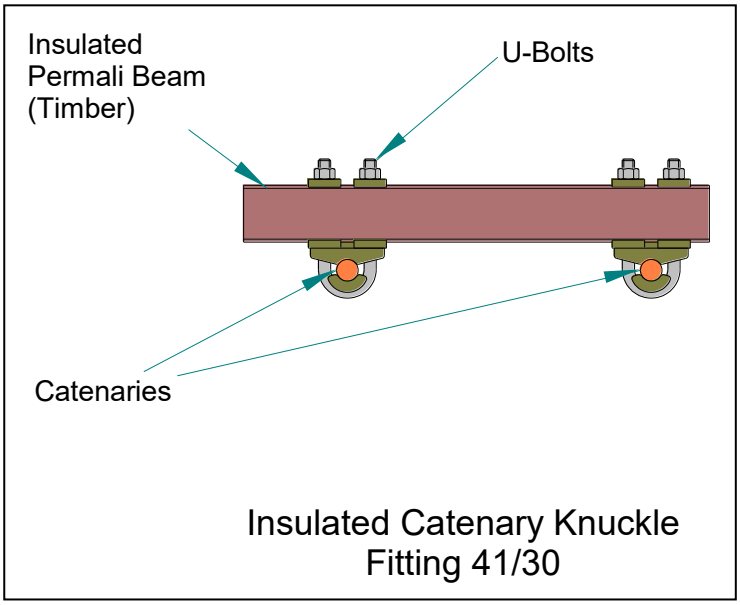


Figure 114 - Permali Insulated Catenary Knuckle

Refer to *Figure 114* which identifies the main parts of the catenary insulated knuckle, using permali as the insulator. Note that having the U-bolts orientated with their fastening nuts located on top tends to avoid trapping moisture, and in doing so makes them or other connected parts much less likely to corrode over time or the permali timber to rot in that area.

Figure 115 shows an instance with both catenary and contact insulated knuckles installed, probably located at one end of an overlap bay. The permali beams are painted white.

Note the presence of the single pull-off arm, which is intended to give the correct stagger to the arrangement and hold it there, especially under windy conditions.

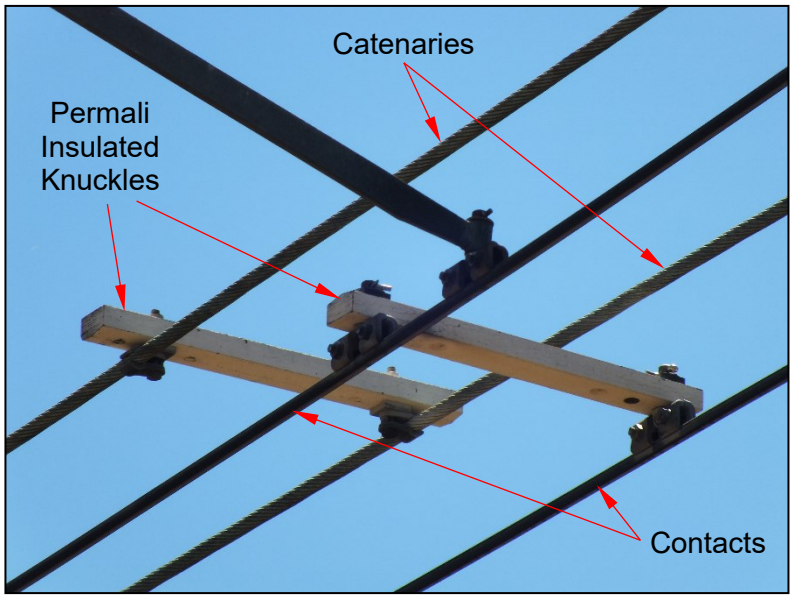


Figure 115 - Insulated Catenary & Contact Knuckles

At Diamond Crossovers

The tracks at a diamond crossover intersect at a considerable angle, and the servicing contact wires need to be suitably located above the tracks for pantograph security throughout the crossover. This is an undesirable situation for the OHW, and in this awkward junction area the best configuration to cope with this is a *flat contact arrangement* (i.e. same contact heights throughout), in order to promote a smooth pantograph passage throughout the crossover and to minimise any wear on contact wires and pantographs.

The contact wires in a flat contact arrangement *do not cross*. So a wire (contact or catenary) comes into the crossover, passes near the other contact wire and then it goes out on the same side – see *Figure 116* for what I mean. This action results in a huge radial load if only 1 knuckle were to be installed where they tie together. So, it really requires 3 or 4 contact knuckles to be installed and configured so that they each equally *share* the radial loads to a much lower and more tolerable amount. Such equitable sharing is achieved by having the same *change in angle* of the wire at each knuckle attachment point, e.g. 175° across each attachment.

Steel knuckles can be used if both sides are the same electrical section and employ many feeder jumpers. More commonly however, these special crossovers need to be insulated – one side from the other – and for both the contact and its supporting catenary. This means having different electrical section numbers, but it then allows more discriminant electrical protection for improved reliability for train running (among other benefits).

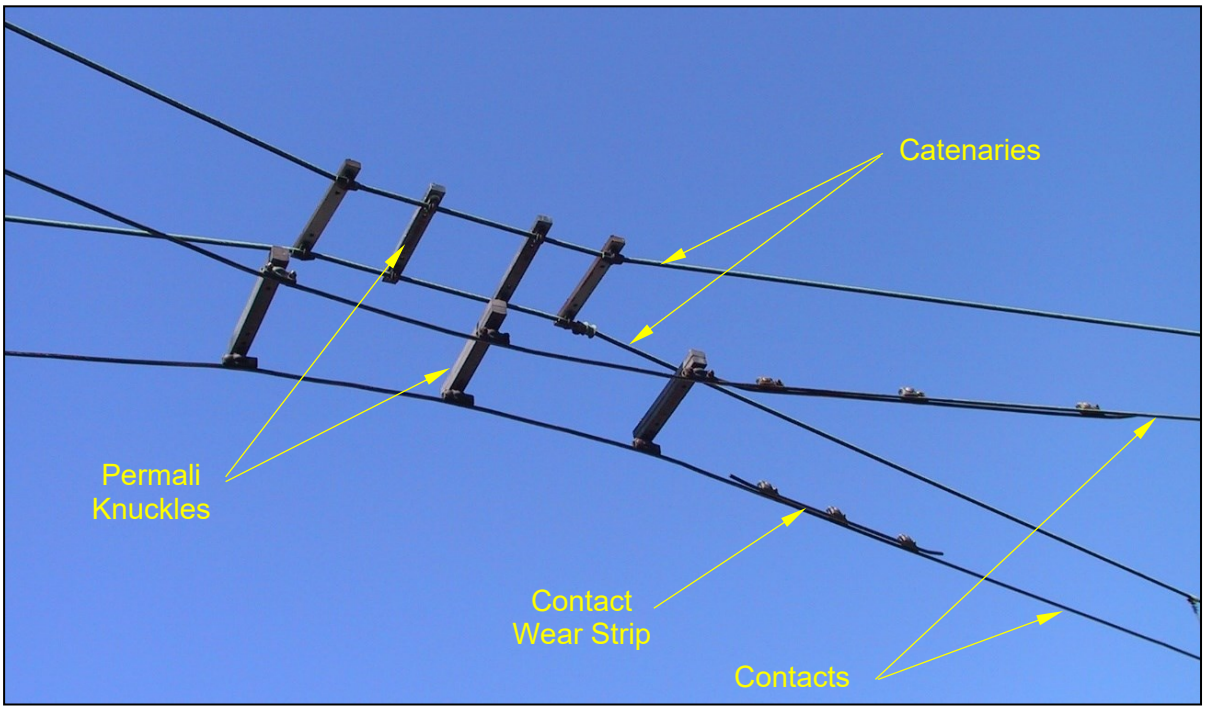


Figure 116 - Insulated Permali Knuckles at Diamond Crossover (viewed from below)

Permali Insulated Knuckles

In the past, permali beam was used for the insulating medium in these situations. Refer to *Figure 116* which shows permali beam knuckles being used in both the catenary (4 units) and contact (3 units).

The lower radial loads in each knuckle can be readily handled by each insulated knuckle unit without becoming mechanically overloaded. This is especially important for their reliable, long term operation (measured in decades).

So, as mentioned above, ideally each insulated knuckle (contact or catenary) should be configured to see the same *change in direction* of wire at that knuckle – they need to *share* the radial loads equally. In this way, no one unit sees more radial load than the others. (Note that it's the change in wire direction from a straight line, when under tension, that determines the amount of radial load in the wire at that point. The greater the change in direction, the greater the radial load.)

This means that the geometry of the whole arrangement needs to be designed correctly, i.e. the spacing between successive knuckles needs to be set, as well as the variable distances

between connected contact (or catenary) wires on each knuckle. See *Figure 119* further on for an idea of typical setting-up distances for a group of insulated knuckles.

Also, the radial loads at both ends of each insulated knuckle unit must balance, otherwise the arrangement will shift laterally into an equilibrium position, which may or may not provide acceptable staggers for pantograph security through the crossover. So, if the 2 contact runs have different tensions, then this needs to be factored into the design to get the correct staggering throughout the crossover.

Lastly, even if all the knuckles equally share the radial loads, the outer 2 knuckles will experience a far greater wind load, due to the length of exposed wire to the previous or next registration location.

Note:

A keen eye will observe that there are a few problems with *Figure 116*. The 3 contact knuckles appear to be sharing the radial loads equally (the changes in wire direction seem to be the same) and this is good. However, the 4 catenary knuckles are not sharing the loads – the 2 outside units are taking full radial load while the inner 2 units are taking virtually none because the catenary wire is in a straight line at their connection points. This means that the outer 2 catenary knuckles are more likely to become overloaded in time, and are thus more likely to eventually fail (as the condition of the permali timber slowly deteriorates). The 2 inner catenary knuckles have added no value, but the huge size of the overall radial load should demand that all 4 knuckles share this burden equally.

Also, in reality, the number of knuckles should have been swapped – 4 knuckles for the contact and 3 knuckles for the catenary. This is because the contact wire directly interfaces with the pantographs and having more knuckles would help cope with the far greater mechanical disturbance as pantographs pass through. Also, the contact wire undergoes a much higher tension change with temperature than the catenary wire. So, it's highly likely that the tension (and therefore the radial loads) on the contact wire at -5°C would be higher than for the catenary at that temperature.

In *Figure 116*, it is likely that the trains travel in the direction from right to left, given the location of the 2 contact wear strips which are normally needed on the *approach-side* of the arrangement if the (uplifted) edge of the pantograph *abruptly hits* the adjacent contact wire.

However, depending on the relative impedances from substation, and on the surrounding train loads at the time, a train pantograph can strike an arc as it *departs* the insulated knuckle arrangement – the wire leaving the pantograph can draw this arc (a bit like what happens with arcing horns, but these horns are normally positioned vertically). Even though any arc here would naturally extinguish quickly, it can lead to metal erosion on the copper contact wire over time, and it may therefore be necessary to install wear strips on the *departure side* as a consequence, if this is found to be a consistent problem.

Cycloaliphatic Resin Insulated Knuckles

More recently, *cycloaliphatic resin* insulators have been incorporated in contact knuckle arrangements, as shown in *Figure 117*, *Figure 118* and *Figure 119*.

These newer knuckles were developed for both the Central Flyover and Flyunder tracks in the early 2000s when all the surrounding wire was renewed and regulated (from Goulburn St to Redfern).

This arrangement uses the "Siemens" brand resin insulator, which has huge tensile, compressive, torsional and bending stress ratings.

Even though one such insulator could have handled the contact radial loads, this newer contact knuckle arrangement used 2 insulators in parallel. This is because there is only 1 connecting bolt on each side of this insulator, so if only one insulator is used, there can be a tendency for these bolts to twist and become loose as the pantographs pass through and twist the knuckle (as it picks up the adjacent contact wire). Employing a connecting plate at each end with 2 bolts connecting 2 insulators in parallel, effectively eliminates this potential problem.

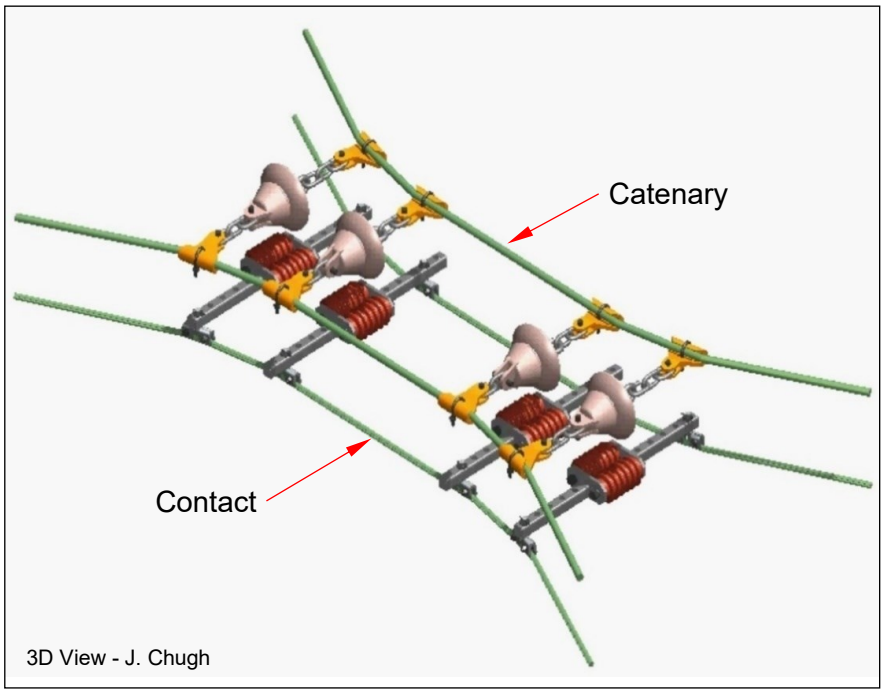


Figure 117 - Insulated Knuckle arrangement at a Diamond Crossover

The layout view of this arrangement is depicted later on in *Figure 671*.

Not only does this arrangement place a huge *tensile load* onto each insulator, it also introduces a significant *bending stress* as well (due to the vertical height distance, from the centres of opposing contact wires, to the centre of insulators).

So, having 2 resin insulators working in parallel also effectively places half the bending stress on each insulator, which is good for the long term survival of this important arrangement.

Figure 118 - Insulated Knuckle arrangements at Central Flyovers

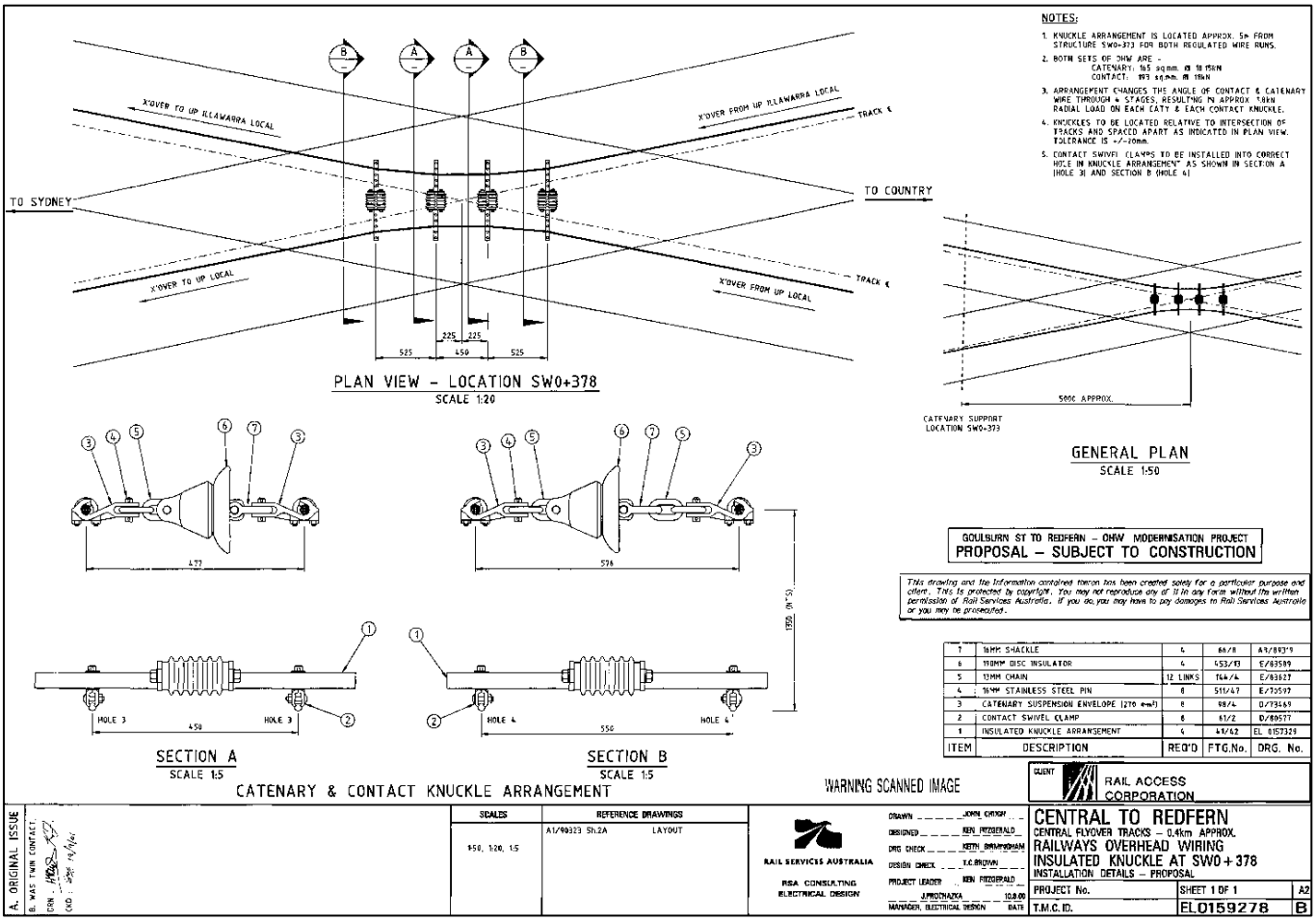

NOTES:
1. KNUCKLE ARRANGEMENT IS LOCATED APPROX. 5m FROM STRUCTURE SW0+373 FOR BOTH REGULATED WIRE RUNS.
2. BOTH SETS OF OHW ARE -
CATENARY: 165 sq mm. @ 15kN
CONTACT: 193 sq mm. @ 15kN
3. ARRANGEMENT CHANGES THE ANGLE OF CONTACT & CATENARY WIRE THROUGH 4 STAGES, RESULTING IN APPROX 15kN RADIAL LOAD ON EACH CATY & EACH CONTACT KNUCKLE.
4. KNUCKLES TO BE LOCATED RELATIVE TO INTERSECTION OF TRACKS AND SPACED APART AS INDICATED IN PLAN VIEW. TOLERANCE IS +/-10mm.
5. CONTACT SWIVEL CLAMPS TO BE INSTALLED INTO CORRECT HOLE IN KNUCKLE ARRANGEMENT AS SHOWN IN SECTION A (HOLE 3) AND SECTION B (HOLE 4)
X'OVER TO UP ILLAWARRA LOCAL
X'OVER FROM UP ILLAWARRA LOCAL
TRACK 4
TO SYDNEY
TO COUNTRY
X'OVER TO UP LOCAL
X'OVER FROM UP LOCAL
TRACK 3
225 225
525 450 525
PLAN VIEW - LOCATION SW0+378
SCALE 1:20
5000 APPROX.
CATENARY SUPPORT LOCATION SW0+373
GENERAL PLAN
SCALE 1:50
GOULBURN ST TO REDFERN - OHW MODERNISATION PROJECT
PROPOSAL - SUBJECT TO CONSTRUCTION
This drawing and the information contained thereon has been created solely for a particular purpose and client. This is protected by copyright. You may not reproduce any of it in any form without the written permission of Rail Services Australia. If you do, you may have to pay damages to Rail Services Australia or you may be prosecuted.
HOLE 3
450
HOLE 3
HOLE 4
550
HOLE 4
1950 (N°S)
SECTION A
SCALE 1:5
SECTION B
SCALE 1:5
CATENARY & CONTACT KNUCKLE ARRANGEMENT
WARNING SCANNED IMAGE
7 16MK SHACKLE 4 66/8 A3/8037
6 110MM DISC INSULATOR 4 453/83 E/83589
5 13MM CHAIN 12 LINKS 744/4 E/83827
4 16MM STAINLESS STEEL PIN 8 511/47 E/70597
3 CATENARY SUSPENSION ENVELOPE (270 mm²) 8 98/4 D/73469
2 CONTACT SWIVEL CLAMP 8 61/2 D/89577
1 INSULATED KNUCKLE ARRANGEMENT 4 44/62 EL 0157329
ITEM DESCRIPTION REQ'D FTG.No. DRG. No.
CLIENT
RAIL ACCESS CORPORATION
A. ORIGINAL ISSUE
SCALES
1:50, 1:20, 1:5
REFERENCE DRAWINGS
A1/98323 Sh.2A LAYOUT
RAIL SERVICES AUSTRALIA
RSA CONSULTING ELECTRICAL DESIGN
DRAWN JOHN CHOW
DESIGNED KEN FITZGERALD
DRG CHECK KEITH BRAMINGHAM
DESIGN CHECK T.C.BROWN
PROJECT LEADER KEN FITZGERALD
APPROVAL 10.8.00
MANAGER, ELECTRICAL DESIGN DATE
CENTRAL TO REDFERN
CENTRAL FLYOVER TRACKS - 0.4km APPROX.
RAILWAYS OVERHEAD WIRING
INSULATED KNUCKLE AT SW0+378
INSTALLATION DETAILS - PROPOSAL
PROJECT No.
SHEET 1 OF 1
A2
T.M.C. ID.
EL.0159278
B

Figure 119 - Typical Insulated Knuckle application drawing

This arrangement permits the standard contact swivel clamp to be installed directly into one of the several holes spaced 50mm apart and located at each side of the insulator pair. These holes are provided for setting the wire position laterally. (The holes also allow for twin contacts to be installed if required.)

The overall design requires 3 or 4 such contact knuckles installed to equally share the significant radial load imposed by the 2 runs of contact wires that change angles in opposite directions quite dramatically. An individual contact knuckle has little chance of reliably holding the radial load, but having 4 knuckles – appropriately spaced longitudinally apart – can reduce the radial loads to ¼ of this large value. This then becomes a more reliable arrangement which should last a long time (it's more than 20 years so far).

To register the above catenary wires together, the knuckle arrangement uses the standard porcelain side-strain insulator (using different number of connecting links to locate it above the contact wire/s and get the correct geometry so as to again share the radial loads equally).

For this arrangement to work in a regulated OHW system, it should be located close to a fixed anchor or fixed mid-point location. In this way, the contact wires won't move much with temperature, and the 2 runs of contact wires should move at about the same rate as each other (in other words, the overall knuckle arrangement should not rotate by much with temperature).

Note that if side wear becomes evident on the contact wire/s at the forking-in points, this may require sacrificial wear strips to be installed. This action will stop any further wear of the main line contact wires and so prolong their life.

If care is exercised during installation and later during maintenance, the levels and alignment of the contact wires relative to each other can be made to minimise or avoid any such wear, but if wear still occurs then it's back to the wear strips.

3.1.5.5 Design Notes

FATIGUE

The fact that knuckles connect 2 sets of wires (be it catenary-to-catenary or contact-to-contact), and these 2 wires can move in different ways (up/down, laterally left/right and longitudinally towards or away from Sydney), means that fatigue may be introduced if the wrong fittings are called up in the design. So, their installed configuration needs to be carefully thought through.

To help combat fatigue, it is often useful to introduce one or more points of pivoting, through the use of pin connections or the like. In this way any relative movement can be accommodated by rotation of a clamp, rather than bending the catenary or contact wire being connected, or overstressing various clamps. (Bending a wire or strands of a wire may eventually lead to fatigue of the strands and ultimately snap the wire.)

Castings can be particularly vulnerable to developing stress cracks over time. This is likely one of the main reasons why the normal minimum safety factor of 3:1 is increased to 4:1 as mandated in the standards for the use of castings in the design of each situation.

An example of a fatigued catenary knuckle from the compound OHW system is given much later in *Section 5.1.8, Metal Fatigue* – see *Figure 553*. It shows an offending hairline fracture in a formed end of copper tube.

CROSSING CATENARIES

With *fixed-anchored* catenaries that cross each other, the policy is that you either:

- Provide them with plenty of *clearance*, e.g. > 100mm in worst (closest) case, or
- Deliberately *knuckle* them together using a U-bolt clamp.

If the independent catenaries come so close as to touch each other, then there's a strong chance that some current will flow at the connection (depending on the nearby traffic). Here, in addition to some level of frictional wear over time, it can also lead to arcing and damage of the outer strands of both catenaries which can rapidly damage the wires and cause a failure.

With *regulated* catenaries that cross each other, unless there are special circumstances, they must not be tied together. Instead, they need to have at least 50mm of mechanical clearance. Unlike fixed-anchored OHW where the crossing clearance between catenaries can change with temperature, the clearance with regulated OHW is much better controlled, and 50mm is deemed a satisfactory clearance. A feeder jumper or potential jumper is normally installed close by.

But by far the worst situation happens if *one catenary is regulated and the other is fixed-anchored*, in which case calculations need to be made to determine what clearance needs to be (and at what temperature) in order to avoid the wires ever touching. Then installed accordingly.

SHARED LOADING

An insulated knuckle arrangement at a *diamond crossover* is a highly loaded arrangement, because the change in direction of contact wires from incoming to outgoing results in considerable (but balanced) radial loads.

Holding these contact wires that head off in opposite directions, cannot be reliably achieved with just the one insulated knuckle. It typically takes 3 or 4 such knuckles in order to share the radial load among the knuckled and not overload any individual knuckle.

WIRES PARTING WAYS

A fairly common approach in the older fixed-anchored OHW was to have a flat-knuckled arrangement in the contact wires (to suit the pantographs), but have the catenaries above crossing. This meant that the catenary and contact wires of each of the 2 runs parted and went their separate ways at that point.

An example of this approach can be seen in *Figure 120* at North Sydney, where the Up Shore track (right) and No. 2 Platform track (left) come together. Here, trains for both tracks head in the same direction (towards where the photo was taken) and will merge into the single track. And the trains coming out from North Sydney Station (located just inside the air-space development in the background) would likely be travelling at similar speeds when reaching this turnout, but obviously not at the same time.

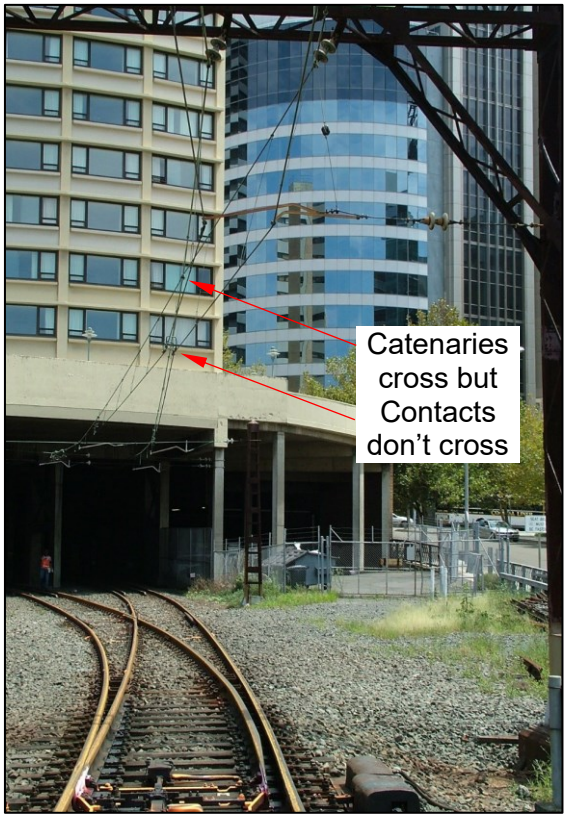


Figure 120 - Catenary and Contact Wires going separate ways

Having a steel flat-knuckled contact configuration – with both contact wires at the same level – aims to provide more even wear on both contact wires at the 2 forking-in points, where the pantograph first meets the adjacent contact wire and picks it up as it passes through.

This more complicated approach *is no longer acceptable*, and it cannot be readily used with Regulated OHW. Note that the situation in this example no longer exists, as all OHW was recently renewed and regulated. Now, both catenary wires cross and both contact wires cross.

3.1.5.6 Status (c. 2014)

N/A.

3.1.5.7 Reference

- *Fixed Knuckle* – see F/32466, F/32467 for contact knuckles.
- *Contact Sliding Knuckle* – see drawing EL0027000 for arrangement (old drawing is E/78019).
- *Insulated Contact Knuckles* – see EL0159278 for instance (at Central Flyover diamond crossover).
- *Insulated Knuckles* – see E/69596 sh. 1 & 2 for contact knuckles.
- *Crossing Knuckles* – see drawing E/72483 for contact knuckle.

3.1.6 Contact Termination Clamps

3.1.6.1 Description

A contact termination clamp is a device installed at each end of a length of contact wire, for the purpose of applying a high mechanical tension to the wire without any slippage.

A run of contact wire from anchor to anchor can have several contact termination clamps. They must exist at both end anchor locations, but they will also be at any points of electrical sectioning (including at pennant insulators and at section insulators). So, there will always be an even number of such clamps in a wire run (although not necessarily all of the same type) – 2 or 4 or 6, etc.

3.1.6.2 Function

A contact termination clamp mechanically connects to the end of a piece of contact wire to *terminate* it. A clamp installed at each end of a length of contact wire can then allow it to be connect to other equipment which will allow it to have a huge continuously-applied mechanical tension to this conductor.

The clamp can normally grip this wire in a way that doesn't cause damage to the wire, and so it can usually be relocated to another position on the wire or reused elsewhere – however there may be exceptions to this.

It is important to note that a pantograph *must not* run along (or come too close to) these clamp fittings – they are not designed to perform this function. Also, they shouldn't normally be configured to carry any traction current through the clamp itself, especially if stainless steel pins, etc. are connected in the current path.

3.1.6.3 Typical Components

Contact termination clamps generally rely on friction to make an effective mechanical connection to the contact wire, without the need for machining the contact wire in any significant way. This makes the connection relatively easy and quick to achieve in the field, which is most important.

The means of applying the friction grip to the wire usually allows for some later position adjustment on the wire (if needed).

The high friction ultimately comes from applying pressure. This pressure can come from wedge fittings with serrated teeth that bite into the contact wire – either to the top of the contact wire or around the perimeter of the contact wire – or it can come from side plates that clamp around the contact wire (which is bent back onto itself).

These methods seem to make for a good mechanical connection, without the need to drill holes into the contact wire itself or deform it in some other significant way (apart from filing the rough edges when the contact wire is cut).

The body of the clamp is usually made from strong metal, such as gunmetal or stainless steel. Bolts are normally stainless steel these days. For obvious reasons, the wedge fittings are made from a metal, typically stainless steel, that's harder than the hard-drawn copper contact wire (or other copper alloys).

3.1.6.4 Configuration

There are several different types of contact termination clamps within Sydney's OHW system, as detailed below.

CONTACT HALF-SPLICE

A "contact half-splice" has a special single wedge fitting that grabs the top of the contact wire to securely hold it to the body of the half-splice when tension is applied. Refer to *Figure 121*.

Figure 121 - Contact Half-Splice connected to Insulator

These fittings are normally installed at anchors, and they are also used in Type 5 section insulators to terminate the mechanical load into their contact insulation. In this situation, the underside of the half-splice is located only about 6mm above the passing pantographs, thus the requirement to have a smooth underside to the splice. (Two of these half-splice clamps are shown as Item 9 in *Figure 396* much further on, along with the ¼" vertical clearance to pantographs in "Section A-A" on this drawing.)

The contact half-splice is fitting number 511/19 and is shown *Figure 121*.

Figure 122 shows a sectional view of what's happening inside the contact clamp that allows it to hold tension.

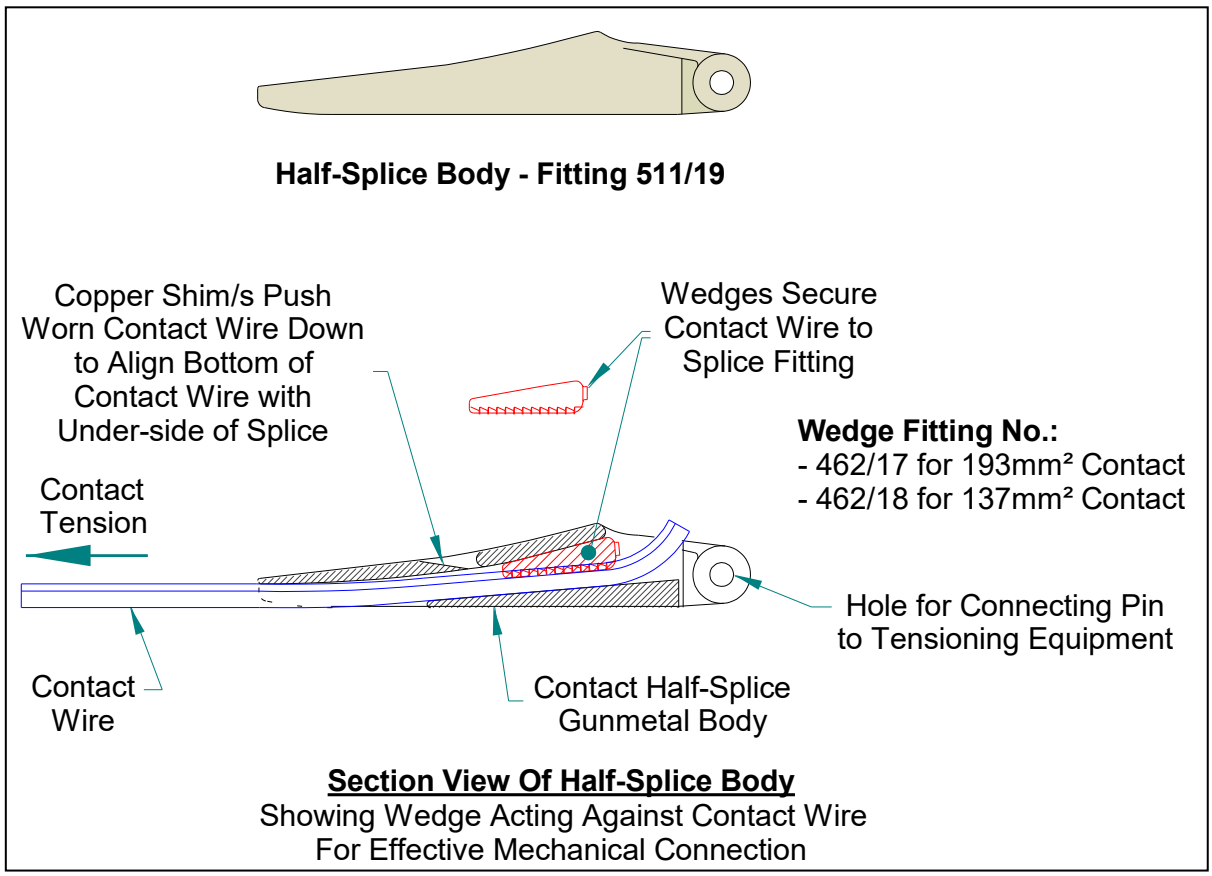

Half-Splice Body - Fitting 511/19
Copper Shim/s Push Worn Contact Wire Down to Align Bottom of Contact Wire with Under-side of Splice
Wedges Secure Contact Wire to Splice Fitting
Wedge Fitting No.:
- 462/17 for 193mm² Contact
- 462/18 for 137mm² Contact
Contact Tension
Hole for Connecting Pin to Tensioning Equipment
Contact Wire
Contact Half-Splice Gunmetal Body
Section View Of Half-Splice Body
Showing Wedge Acting Against Contact Wire
For Effective Mechanical Connection

Figure 122 - Contact Half-Splice (with section view)

This clamp suits both the 137mm² and 193mm² contact wire sizes, and includes:

- The *gunmetal body*, with a pair of 17mm holes drilled in-line at one end for connecting to another piece of equipment using a standard 16mm stainless steel pin, which transfers the mechanical load elsewhere.
- A special single *wedge fitting* (made from stainless steel) which has a series of teeth that bite into the top of the contact wire to securely hold it when tension is applied. There's

one size wedge for 137mm² contact wire (fitting 462/18) and another for the larger 193mm² contact wire (fitting 462/17).

- Special copper *shims* may also be required as a packer to terminate the contact wire if it has been worn where a connection is needed. (Fitting 462/6 is about 1mm thick and 462/16 is about 2mm thick.) The shims are placed between the clamp and the top of the worn contact wire, which pushes the bottom of the contact wire into bottom of the splice body for proper fitting alignment.

Note that the contact half-splice fitting has been deemed not suitable for future use in 2010. They are used in Type 5 SIs, so these are likely no longer to be installed too.

FORKED COLLAR SOCKET

The more recent contact "forked collar socket" has a collar that slips over the contact wire, and this collar has multiple annular wedges that effectively grab the circumference of the contact wire uniformly. As tensile load is applied, the wedge action of the annular collar grips the contact wire more firmly.
Refer to *Figure 123*.

Figure 123 - Forked Collar Sockets for the 2 Contact Wire sizes

The forked collar sockets shown in *Figure 124* and *Figure 125* are available for both the 137mm² contact wire size (fitting 462/19) and the 193mm² contact wire size (fitting 462/20). They comprise:

- The stainless steel body, with a pair of 17mm holes drilled in-line at one end, for connecting to another piece of equipment using a 16mm stainless steel pin, which transfers the mechanical load.
- A special *collar* made from some strong copper alloy that closely matches the contact wire size, and slips over this wire. This collar has a series of internal annular teeth that bite into the perimeter of the contact wire for effective grip.

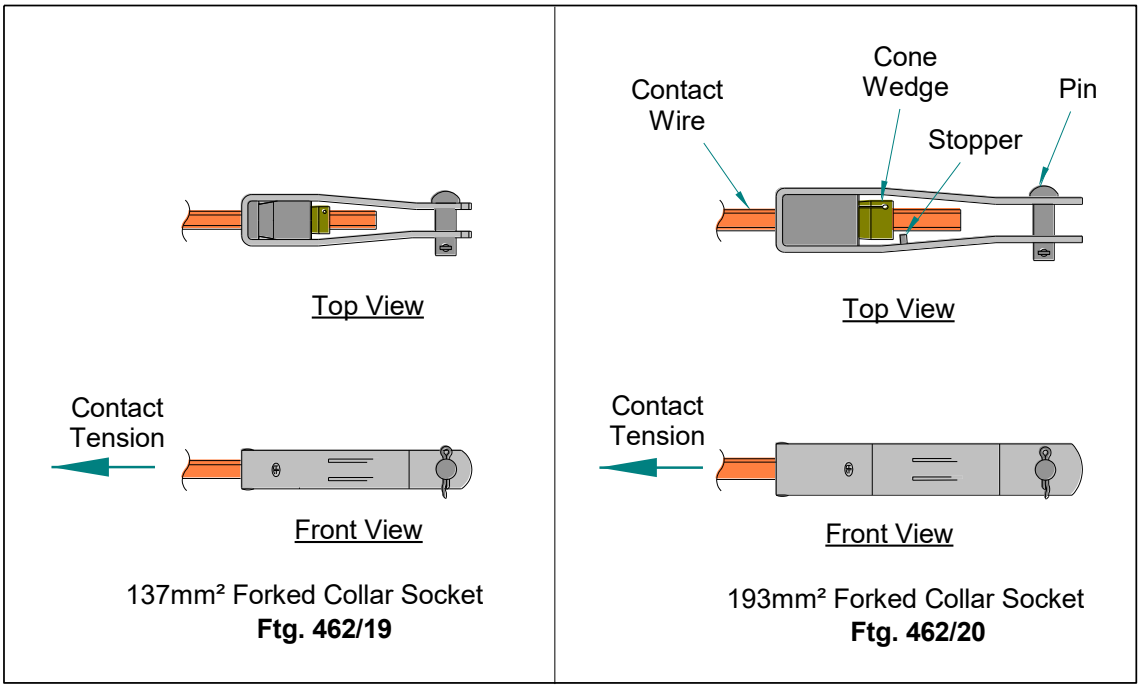


Figure 124 - 137mm² & 193mm² Contact Forked Collar Sockets

The correct forked collar socket must be used for each of the 2 contact wire sizes (137mm² and 193mm²). They are not interchangeable. Also, the manufacturer advises that the collar itself should be discarded and renewed if the forked collar socket is to be reused elsewhere.

As with the contact half-splice, the forked collar socket fittings are designed such that the higher the tension that's applied, the greater the gripping action that takes place by the wedge action onto the contact wire, making for a very effective mechanical termination.

Figure 125 - 193mm² (top) & 137mm² (bottom) Forked Collar Sockets

SERRATED CLAMP

"Serrated clamps" accompany the Type 6 section insulator as supplied from the European manufacturer. They are used for connecting the contact wires to the cast aluminium SI body – refer to *Figure 126*.

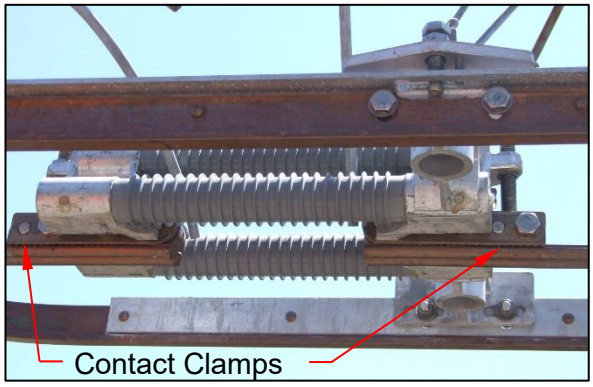


Figure 126 - Underside of Type 6 SI showing Contact Clamps

This clamp initially required special approval because it was the only one in the system (at that time) that *gripped* to the contact wire's wedge shape. There was uncertainty about how effectively the contact wire could be gripped, especially considering the large 193mm² contact size and the huge mechanical tensions applied to it (which were likely much higher than those encountered overseas).

As depicted in *Figure 127*, serrated teeth on both sides of the clamp bite into the contact wire grooves as these sides are tightened with their 4 bolts. The bolt heads alternate on both sides for a more effective total grip. Special copper shims are available to further separate the sides to suit the larger 193mm² contact wire size.

Figure 127 - Under-side of Type 6 SI Contact Clamp

It may be that this clamp is still the only clamp with serrated teeth that's approved for use in Sydney's system (but this would need confirming).

BOLTED CONTACT CLAMP

An older "bolted contact clamp" style fitting terminates the contact wire as shown in *Figure 128*.Apparently the contact wire passes between a pair of side plates and is then bent back on itself. The side plates are compressed together by tightening 6 bolts, which then secures the contact wire.

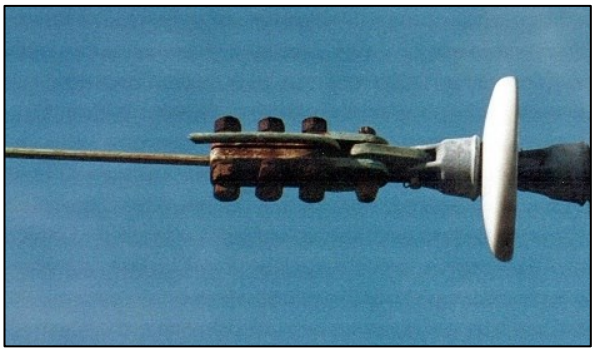


Figure 128 - Bolted Contact Clamp

This clamp can only be used in wire that's well and truly out-of-running.

Thankfully this is a relatively rare piece of equipment to see these days (along with varying degrees of surface rust). It's no longer used.

3.1.6.5 Design Notes

For the various clamps to perform their task of gripping the contact wire to the body of the clamp (then connecting other parts to this body through a hole/pin), there should not be any impediments to the clamping (friction) action.

For example, the wedge in the contact half-splice fitting must be able to slide in its cavity and:

- Make an effective friction connection between the serrated bottom of the stainless steel wedge against the top of the contact wire, and
- Have a smooth surface connection with little friction between the top of the stainless steel wedge and the corresponding inside surface of the half-splice gunmetal casting.

See *Figure 129* (further on) for the same mechanism as used in the full-splice arrangement. The bottom of the wedge has significant serrations that bite into the contact wire, however the top of the wedge is smooth to allow it to move further along for a firmer grip if needed as more tension is applied to the contact wire. If the wedge was somehow prevented from moving further along as more tension is applied, this could lead to the wedge losing its tight grip on contact wire and the wire slipping through, with dire consequences.

I understand that sometimes grease is used to help the smooth side of the wedge or serrated cone to move to its required position under tension, even though this can seem a somewhat contradictory thing to do (using grease to add friction!?). Note that grease is rarely used in OHW because it seems to capture any nearby dust and dirt, which can be counterproductive.

3.1.6.6 Status (c. 2014)

Contact terminations:

- Contact half-splices are no longer to be used in new OHW (its drawing was marked "Not For Future Use" in 2010). To be replaced by the correct forked collar socket fitting.
- Forked collar sockets are to be used for all future installations.
- Older style bolted contact clamp fittings are not to be used in future.

3.1.6.7 Reference

Contact half-splice – Fitting 511/19 – drawing C/83607 ("Not For Future Use").

Forked collar socket:

- Fitting 462/19 (for 137mm² contact wire) – drawing EL 0015239,
- Fitting 462/20 (for 193mm² contact wire) – drawing EL 0015240.

For Type 6 SI termination clamps see the standard drawing EL0166884.

3.1.7 Contact Splices

3.1.7.1 Description

Contact splices are devices that join contact wire to contact wire, in a way that permits the smooth, uninterrupted passage of pantographs (most often travelling at significant speed).

They are typically made from a gunmetal or brass casting, and are mostly used when the contact wire is damaged and needs to be repaired in some way in a localised area.

They can be located anywhere within the wire run, with the contact wire either in-running or close to being so. But they need to be properly aligned for the pantograph to run on the underside of the contact wire (and not brush against the side of the splice).

3.1.7.2 Function

The contact splice is a device installed onto the contact wire to allow this wire to be cut and reterminated. This can be due to worn or damaged wire, and often requires a length of new contact wire to be installed (needing 2 full-splice fittings – one installed at each end of the new wire being inserted) – see *Figure 73* further back (between 1st & 3rd yellow arrows).

The contact splice must be capable of mechanically holding the contact tension, and need to also pass the heavy dc currents in the OHW system by providing a very low resistance joint.

This clamp is installed *onto* the contact wire – there is no need for special machining of the contact wire, and so they can be installed relatively quickly on site and are reasonably reliable (although some can be quite heavy).

The splice needs to be installed in a way that does not interfere with the smooth passage of pantographs. Generally speaking, if there are any signs of arcing at a contact splice when a pantograph passes through, it means the splice is no longer properly set up, and the situation is likely to deteriorate quickly as the arcing erodes the metal.

In addition, if this arcing takes place near peoples' homes, the bright flashes can become a huge annoyance (and particularly at night-time when people are trying to sleep).

3.1.7.3 Typical Components

A contact splice consists of a body component and needs to have some form of wedge component that bites into the copper contact wire to form an effective mechanical connection under extremely high tensions.

There are some other (unapproved?) splices that grip the upper wedge shape of the contact wire (to keep the fitting above and well clear of passing pantographs). They have rows of teeth that bite into this wedge shape. A number of bolts clamp the body onto the contact wire to prevent it from slipping through under the considerable applied tensions in the contact wire.

3.1.7.4 Configuration

There are 2 main ways to reconnect a contact wire, holding the extremely high mechanical tensions and done in a way that allows a smooth pantograph passage:

a) Using a pair of single *wedges*. These single wedges have teeth that bite into the top of the contact wire – the more the tension is applied to the contact wire, the more the serrations bite into the contact – resulting in a very secure connection. See *Figure 129* for example. See "Contact Full-Splice" and "Side-By-Side Splice" below.

b) Using a *bolted clamp* installed on top of the contact wire, with serrations in the lower part of the clamp that bite into the contact wire's upper wedge.

CONTACT SPLICE (OR FULL-SPLICE)

This splice (fitting 462/8) connects 2 contact wires in the same line of action. It's intended for quick repair of a highly-worn, damaged or snapped contact wire. See *Figure 129*.

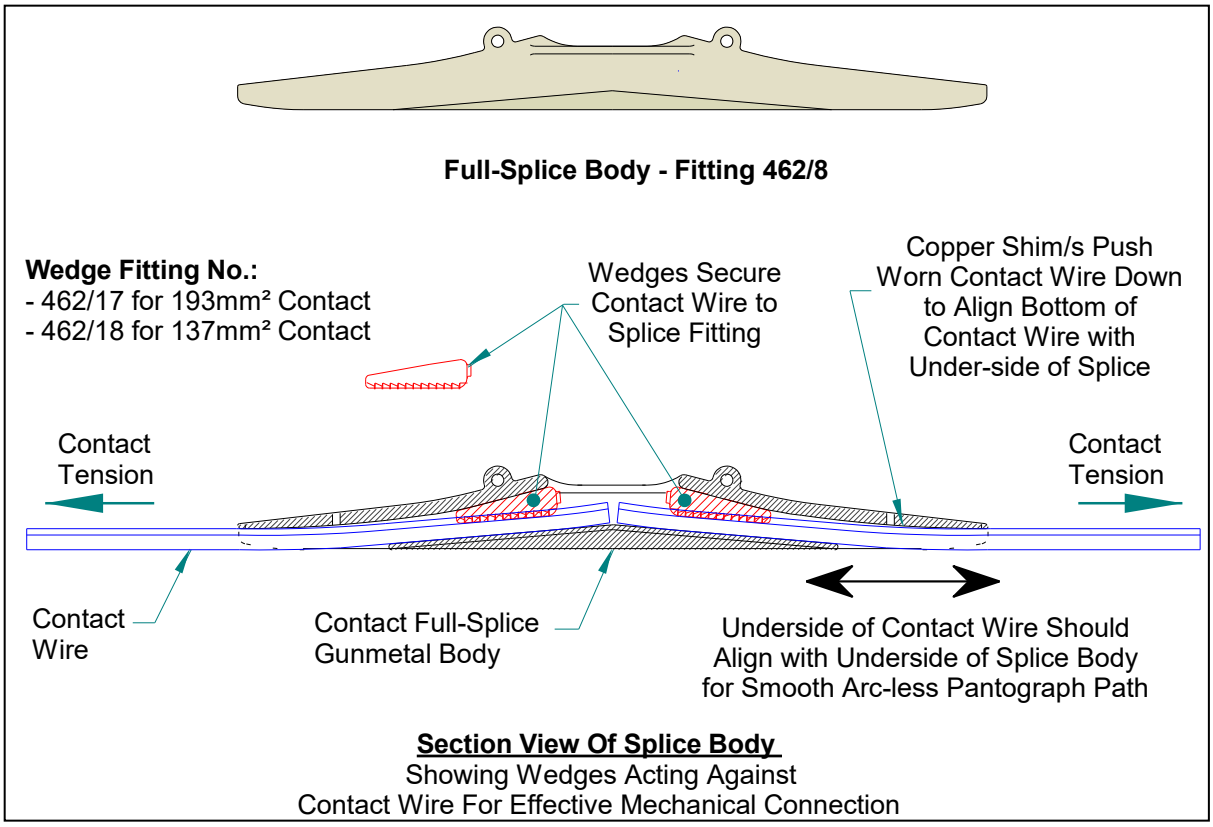

Full-Splice Body - Fitting 462/8
Wedge Fitting No.:
- 462/17 for 193mm² Contact
- 462/18 for 137mm² Contact
Wedges Secure Contact Wire to Splice Fitting
Copper Shim/s Push Worn Contact Wire Down to Align Bottom of Contact Wire with Under-side of Splice
Contact Tension
Contact Tension
Contact Wire
Contact Full-Splice Gunmetal Body
Underside of Contact Wire Should Align with Underside of Splice Body for Smooth Arc-less Pantograph Path
Section View Of Splice Body
Showing Wedges Acting Against
Contact Wire For Effective Mechanical Connection

Figure 129 - Contact In-Line Full-Splice (with section view)

The splice body is a gunmetal casting which accepts both 137mm² and 193mm² contact wires.

The separated contact wires pass into each end. A wedge is installed for each end, and is forced into place using a wedge punch and hammer. This restrains the contact wire from being removed from the splice. Tension is then applied – the tighter the pulling force on the contact wire away from the splice, the more effectively each wedge binds the splice to the contact wire.

There are 2 sizes of wedge fittings – one for each contact wire size. A round spigot is located at the end of the 137mm² wedge for identification purposes, as seen in *Figure 130*.

Standard shims (made from thin copper strip) are used in conjunction with the full-splice fitting to ensure that the bottom running edge of the worn contact wire is flush with the underside of the splice, thus helping to provide a smooth pantograph transition over the splice. A rectangular hole is provided in the casting near each end of the full-splice, which allows the shim to be bent up and around, and similar at the mouth, to retain the shim, as shown in *Figure 130*.

If a smooth pantograph path is not achieved, this can result in excessive arcing if trains draw heavy current as they pass, and this arcing eventually leads to metal erosion and shortened life of the fitting. Any consequent bright flashes of light can also be annoying to the neighbours.

The terminated contact wires are sometimes bent back on themselves because some people think this adds to their security. However, care needs to be exercised to ensure that the wedge is sufficiently free to do its clamping work effectively – it is the wedge that's designed to secure the contact wire to the clamp, *not* the bent contact wire. So, bending back the contact may give the wrong impression of what's actually taking place.

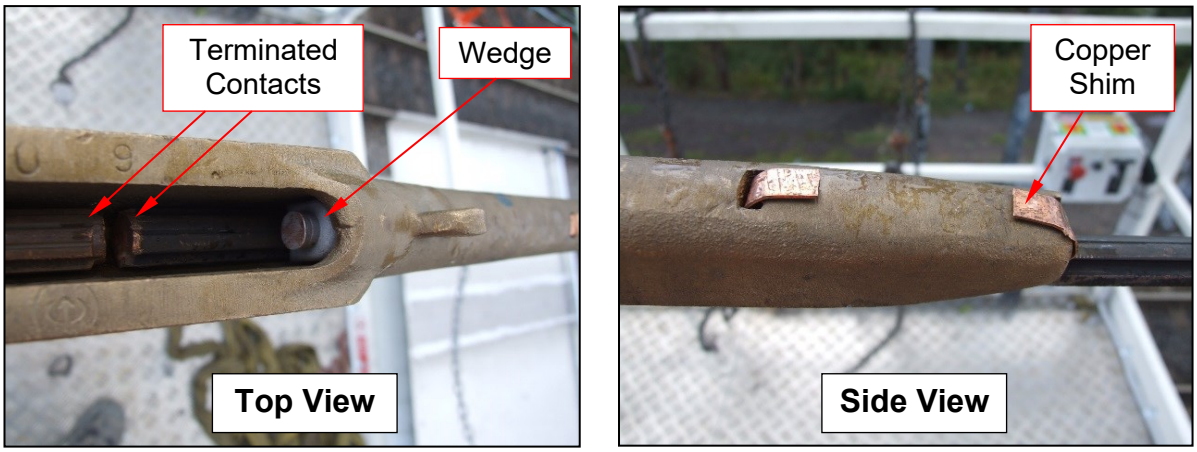


Figure 130 - Contact Full-Splice showing installed Wedge (left) & Shim (right)

A pair of holes is provided in the casting at the top (near the centre of the body). It is likely that these were used for connection to droppers, in order to help support the heavy weight of this fitting from the catenary wire, under the slack tension at high temperatures (~2kN) of a fixed-anchored OHW system. In certain circumstances, this situation could have otherwise produced quite a bit of sag between the adjacent droppers, and exacerbated any pantograph arcing problems.

These holes don't appear to be used at all these days, and there's no need anyway if installed on a regulated OHW system.

This full-splice is the current preferred arrangement, and has been in use for many decades, even though it is a somewhat bulky item (it's sometimes referred to as a "battleship splice").

One of the keys to its success is its relatively long length and slender width, which helps pantographs to approach and pass through this fitting at speed (although its significant weight tends to counteract this benefit to a small degree).

For twin contact OHW, it is good practice to offset the location of the splices in each contact wire so that pantographs do not encounter them both at the same time, as this could otherwise cause significant arcing. They should be displaced longitudinally by at least 500mm or so.

Figure 131 - Underside wear

Figure 131 shows the underside of a full-splice, and the way it too can wear in time. Eventually the splice itself will need replacing after it has reached its wear limit, so it's important to know what this limit is, and to maintain close inspections when it approaches the wear limit. Otherwise it can suddenly break, drop the contact wire and stop trains.

Figure 132 shows a comparison of an unworn contact wire (left) against an extremely worn wire that was installed at a contact splice that was seeing a lot of use (Macdonaldtown, August 2000). This would have been in a similar situation to that of the worn full-splice of *Figure 131*. The heavily worn portion was about 200mm long, and it became so thin that it eventually snapped under the resulting high stress in the wire at winter time. This worn wire can be somewhat hidden, which is why its width needs to be measured to assess the extent of contact wire wear and urgency of repair.

Figure 132 - Worn Contact Wire at Splice

SIDE-BY-SIDE CONTACT SPLICE

This older type of splice (fitting 462/15) is shorter than the in-line splice (above) but seems to have other similar characteristics. See *Figure 133*.

Here, the cut contact wires are installed side-by-side into the body (which is a gunmetal casting), and again wedges hold the contact wires in the body casting.

When contact tension is applied, the casting twists slightly to take up the contact line of force.

The bottom of the splice arrangement (including contact wires) needs to be flat so as to not affect the pantograph passage.

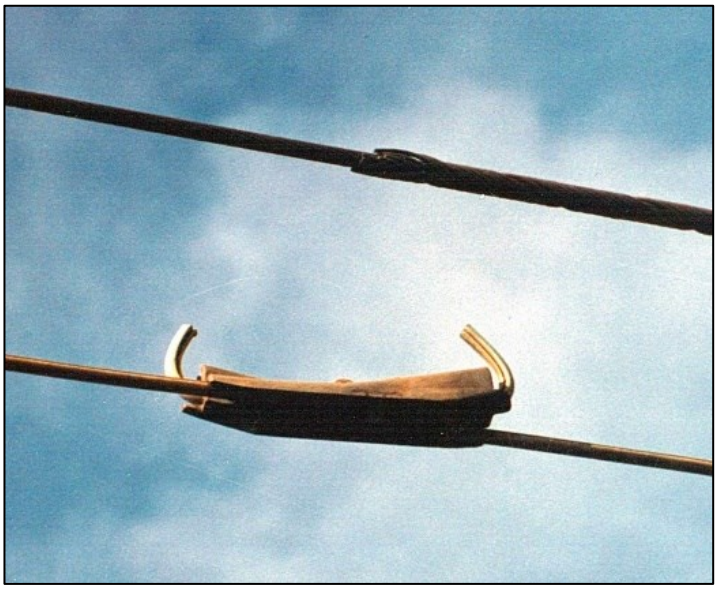


Figure 133 - Side-By-Side Contact Splice

The contact wires are bent upwards and slightly back on themselves. I'm not absolutely sure why this is done – maybe it was thought that it improves security, or to trap the wedges should they somehow become loose (a good idea).

There seem to be some adverse aspects to this fitting:

- Because in this arrangement the contact wires overlap to a certain extent and the contact wires are bent upwards, a small length of original contact wire is taken away from within the bay. In a fixed-anchored system, this may cause problems with contact tension unless additional wire length is gained from somewhere else (e.g. at anchor, but this could be many hundreds of metres away!).
- Compared to the full-splice arrangement above, the length of this arrangement is relatively short, and with a very small lead-in and lead-out, which is not that good for any fast passing pantographs.
- Unfortunately, it has a comparatively wide body, which needs to be properly aligned laterally – ideally the width of its bottom running surface needs to be parallel to the superelevated track (but there is no adjustment). And it also poses a reasonable point load on the contact wire.

These somewhat adverse aspects seem to combine to an extent that pantographs on fast trains can be affected when abruptly encountering this fitting, even if it seems perfectly installed. The consequences can be arcing and premature contact wear in the immediate vicinity, and wear on carbon strips (although modern pantographs are better able to trace the contact wire without arcing).

All in all, this clamp is not a desirable arrangement. It is no longer used.

BOLTED CLAMP CONTACT SPLICE

Various manufacturers make contact splices which are designed to clamp to the butted contact wires being spliced, using a clamp with a series of serrated teeth that bite into the contact wire's upper wedge shape. A piece of the same contact wire is usually installed in the same fashion along the top of the clamp, and the device is clamped on both sides to both upper and lower contact wires using a number of stainless steel bolts. Refer to *Figure 134*.

At the time of my retirement in 2014, investigations were under way to determine if serrated clamps were suitable for use in a contact full-splice arrangement, because of the advantage of reduced weight and apparent ease of installation. (This is even though the Type 6 SI uses them successfully and there have not seemed to be any problems over the past 35 years since their inception.)

Figure 134 - Bolted Contact Splice (not approved ?) at Glenfield Junction

This type of splice is in common usage overseas. However, manufacturers initially did not have one designed large enough for Sydney's large 193mm² contact size.

But the concern was even with the smaller 137mm² size contact wire in conjunction with its extremely hard metal alloys (e.g. cad-copper). The tensions in a fixed-anchored system are extremely high, and they can also drop to very low values, depending on the temperature in the wire, e.g. 15kN (cold) down to 1.3kN (hot) respectively, per *Table 17*.

This has resulted in uncertainty as to whether the serrated biting action can be a reliable gripping mechanism, day in – day out, and over many decades.

I suspect this is the main reason why they had not been adopted in the past, even though various manufacturers had spruiked their use many times over recent decades.

If *new wire* is joined to *worn wire*, then the underside of the new contact wire will need filing down to a level and over a distance leading up to the connection, in order to ramp into the device and promote sparkless pantograph running.

Apparently, there are some models available on the market that are vertically adjustable, so a worn contact wire can be spliced to a new contact wire, achieving the same common lower running face for proper pantograph performance.

This adjustable splice is the one that holds some appeal. However, the matching of a severely worn 193mm² wire to unworn 193mm² wire may cause some local uneven contact levels and subsequent pantograph arcing, due to the turning moments involved with this piece of equipment, as discussed in *Section 3.1.7.5, Turning Moments*.

Up to 2014, no bolted-clamp *full-splices* had been approved for use within the system, although it is highly likely that they will gain acceptance at some point in the future (possibly with some conditions attached). *Figure 134* shows one such device installed at Glenfield Junction (likely without formal approval).

3.1.7.5 Design Notes

For obvious reasons, contact splices are a necessary evil in the OHW system.

Wherever they are installed, they become an important asset that should be properly set up in the first place, and regularly inspected and maintained correctly into the future. Some consider each splice to be a potential weak spot in the system (affecting reliability).

PANTOGRAPH INTERACTION

In-running contact splices introduce localised areas of the contact wire that normally don't interact well with passing pantographs, especially those travelling at significant speed. So, the following aspects are probably worthy of note (provided the splice is correctly set up in the first place). They are only my thoughts.

- A splice offering a longer approach & departure can be better than one where the pantograph comes to it abruptly.
- A splice with significant weight can be detrimental to this interaction (it changes the contact wire's "compliance" by introducing a "hard spot" in the contact wire).
- The contact tension should remain high at all times. This makes fixed-anchored OHW situations a far worse proposition, especially at hot temperatures (low tensions). In such cases, there may be benefits to support the weight of the splice from the catenary.
- The lateral underside running surface of the splice should ideally remain parallel to the superelevated track. (However, sometimes there's little or no adjustment available to control this orientation.)
- The underside of the contact wire needs to provide a smooth path to the pantograph – both leading into the splice and exiting it. The levels must be the same at the point of junction.
- Sometimes the underside of the contact wire can be filed so as to give a gradual taper over a long distance leading up to or away from the splice (especially if one wire is near-new and the other has a much reduced thickness). This action can help enormously.
- An ill-fitted contact splice installed within a few hundred metres on the departure-side of a station, is likely to receive more punishment and so deteriorate more rapidly in time. This is due to the more intense arcs established by the heavy current drawn as the train rapidly accelerates when leaving the station. These days, this can also happen as a train approaches a station, with the large currents fed back to the OHW from the train's regenerative braking feature.
- The effort involved in improving the pantograph interaction at a splice pays off, because poorly installed splices will cause accelerated contact wear and erosion due to arcing (not to mention ongoing wear or damage to the pantograph).

TURNING MOMENTS

If a new contact wire is spliced into a fairly worn contact wire, then the underside of both wires need to be at the same level, for smooth arc less pantograph travel.

However, even if the undersides line up, there is likely to be a tendency for the splice fitting to rotate due to the centroid forces of new and old wire not being at the same level, and thus causing a turning (rotating) moment:

$$Moment = Tension \times Centroid\ Distance$$

Although the vertical offset between centroids is very small (a few millimetres), the huge tensile forces can cause considerable turning moments in this situation.

Refer to *Figure 135(a)* and *(b)*.

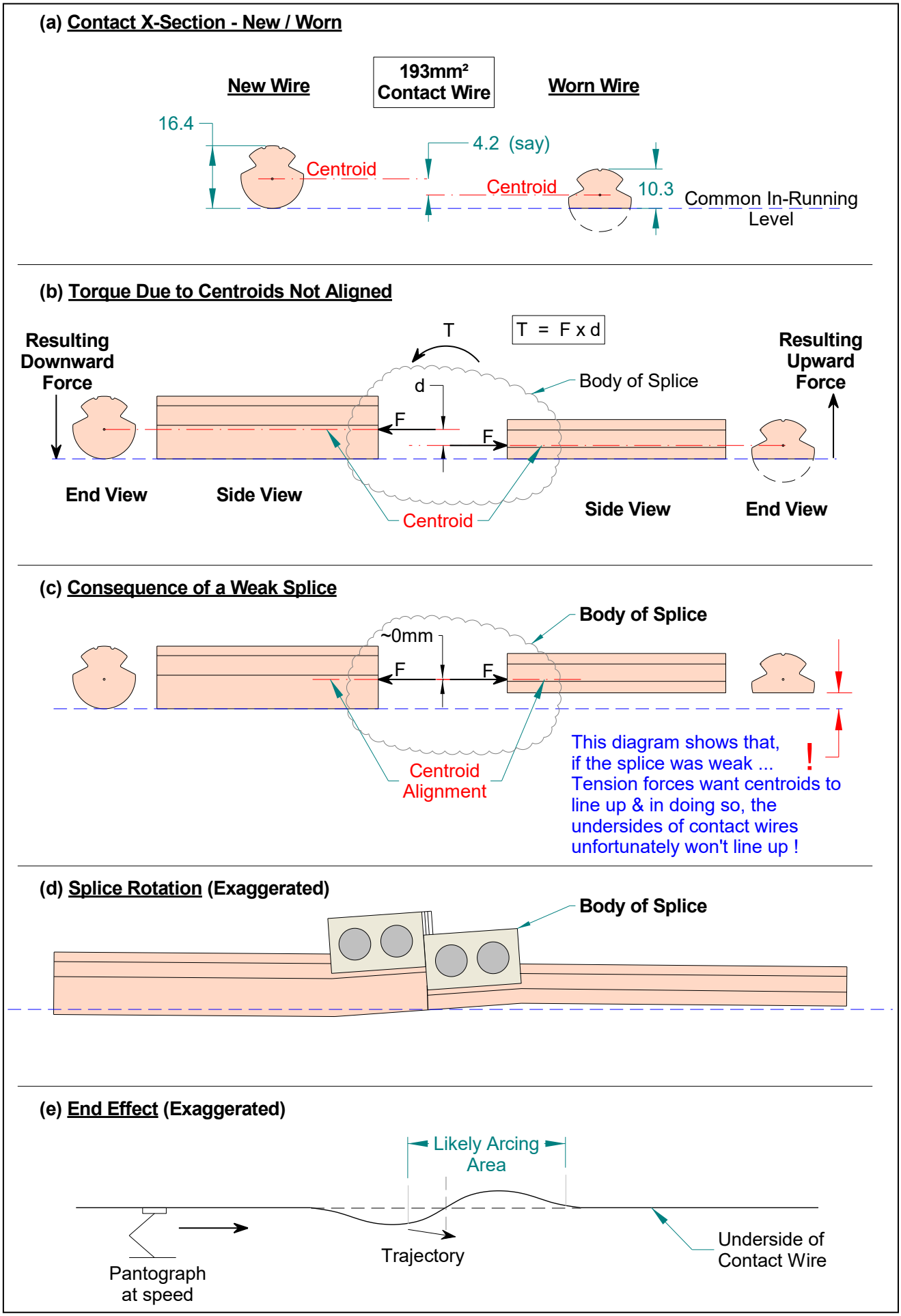


Figure 135 - Consequence of splicing new to old Contact Wire

The turning moment is in the direction that tries to make both centroids line up – *Figure 135(c)*.

The knuckle needs to be strong enough to cope with these forces and moments, but the effect of the moment can be transferred to alter the geometry of the connected contact wires, possibly giving uneven levels in the immediate area – see *Figure 135(d)* (which is much exaggerated to demonstrate the effect).

Figure 135(e) tries to show a likely trajectory of pantograph head travelling at speed, causing arcing.

This rotation effect can make it almost impossible to achieve the perfectly flat running surface required for good pantograph running in the vicinity of the knuckle. If the knuckle is long enough, this effect may be "smoothed" out over the knuckle length, and thus not be so noticeable. In fact, the long length of the existing full-splice arrangement (fitting 462/8), although heavy, tends to perform well in this regard.

Any rotation may cause a disturbance in the contact wire and arcing especially at high pantograph speeds. Lower speeds may be more tolerable and the effects less noticeable.

Newer pantographs, with their ability to better trace the contact wire at high speed, may also be less prone to arcing.

One way to try to combat this effect is to file a taper on the underside of the new contact wire over some distance, to provide a gradual lead into the old contact wire, but this would take quite an effort in order to achieve a satisfactory outcome. Of course, the distance should be longer for higher speed running.

Even though it was a long, heavy and bulky item, the previously mentioned full-splice fitting 462/8 had sufficient length to help spread the effects of this turning moment, and so provided a relatively smooth path with reduced chance of arcing as fast pantographs pass through.

3.1.7.6 Status (c. 2014)

Contact full-splices:

- All contact splicing is to be performed with in-line splices.
- Side-by-side splices are no longer used.

Apart from those used in the Type 6 SI, splices with serrated teeth for gripping the contact wire's upper wedge shape are yet to be approved (?).

3.1.7.7 Reference

In-line full-splice – Fitting 462/8 – drawing D/73780.

3.1.8 Catenary Termination Clamps

3.1.8.1 Description

A catenary termination clamp appears at the end of a length of catenary wire.

In addition, if a catenary wire is cut somewhere within the wire run, it can be joined again using these termination clamps.

3.1.8.2 Function

A catenary termination clamp is designed to effectively hold the high mechanical tensions of the catenary wire, and transfer the load to another piece of equipment (usually through a stainless steel pin of 19mm diameter or larger).

An effective termination should transfer the loadings *within each strand of the catenary wire*, so that no individual strand becomes overloaded.

It is not intended that the catenary termination clamp carry any significant current. Indeed, the termination is usually located next to insulators which prevent such current from flowing.

3.1.8.3 Typical Components

See "Configuration" below.

3.1.8.4 Configuration

Catenary Termination Clamps come in a variety of forms:

- Snail clamp
- Helical anchor
- Forked collar socket
- Bolted clamp

SNAIL CLAMP

The "*snail clamp*" in *Figure 136* is designed to have the catenary wire bend around a gentle radius (so as to not damage the strands), then 3 or 4 wire clips (U-bolt clamps) on the snail clamp are tightened against the catenary to secure it to the clamp.

These clamps were available for 270mm², 327mm² and 510mm² size catenaries.

Figure 136 - Catenary Snail Clamp

The catenary tension line of force continues through the snail clamp to the adjacent termination hardware, with connection via a 19mm diameter stainless steel pin. In this way, the bent catenary tail is under no tension after the last U-bolt clamp. (See *Figure 137*.)

The fittings are:

- *270mm² catenary* – Fitting 281/3 [in gunmetal] and 281/8 [in stainless steel] – refer drawing C/73448.
- *327mm² catenary* – Fitting 281/3 [in gunmetal] and 281/8 [in stainless steel] – refer drawing C/73448.
- *510mm² catenary* – Fitting 281/2 [in gunmetal] and 281/9 [in stainless steel] – refer drawing C/73445.

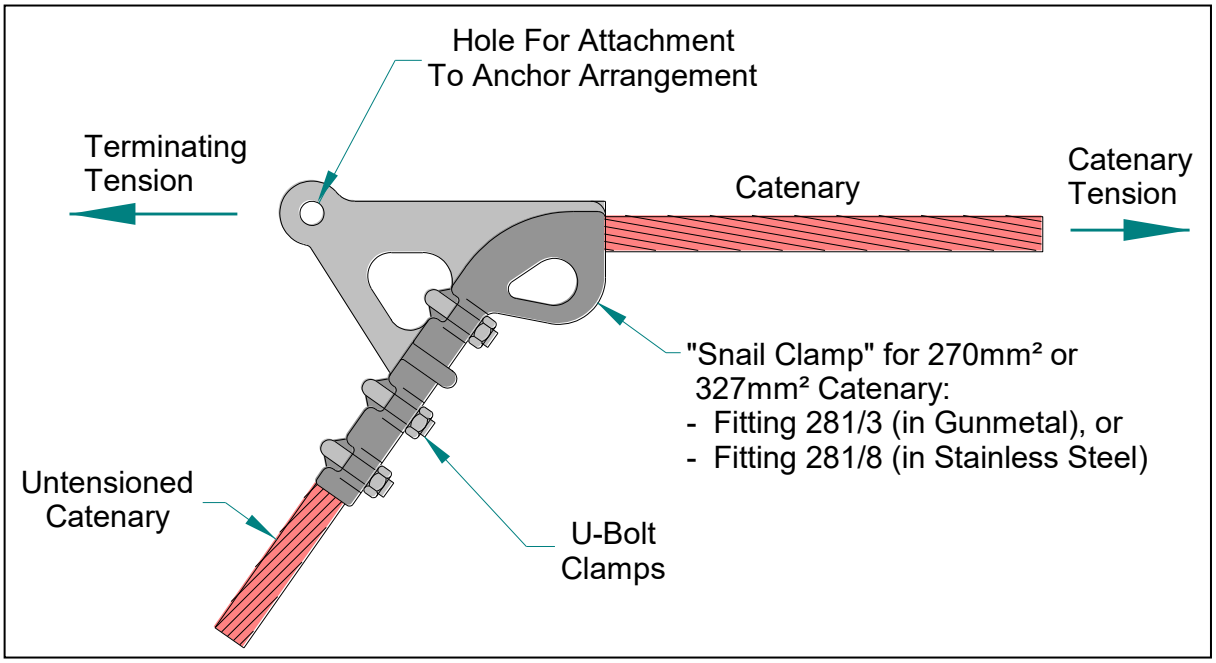


Figure 137 - Catenary Snail Clamp

HELICAL ANCHOR

The "helical anchor" or "wrap-on", as the term suggests, has wire strands of a proprietary copper alloy, that wrap around the outer strands of the catenary wire. The tension in the catenary causes the special strands to tighten their grip on the catenary wire. The more the applied tension, the tighter this grip becomes.

Apparently, the grip is so effective that, if the tension is increased, the catenary wire breaks at its normal breaking load without the wrap-on breaking (at least according to the manufacturers).

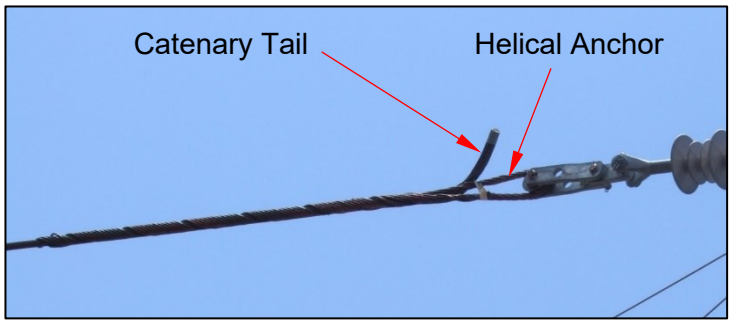


Figure 138 - Catenary Helical Anchor

To install it, one set of strands is wrapped around the catenary, then it passes around a circular thimble fitting (with anchor pin), before returning back to the catenary where the remaining strands again interleave around the catenary. A special "grit" is glued to the inside of the wrap-on strands at manufacture to help adhesion.

Somehow this fitting makes a good electrical connection as well, and the same "wrap around" technique is used in the catenary full-splice arrangement (to repair a catenary) that carries full traction load current in the catenary wire – see next subsection.

According to the manufacturer, once used, they cannot be used again, and should be marked as such and destroyed (recycled for their copper).

As good as they seem to be, there have been failures of this device, as can be seen in *Figure 139*. I'm not aware of the likely cause of this failure.

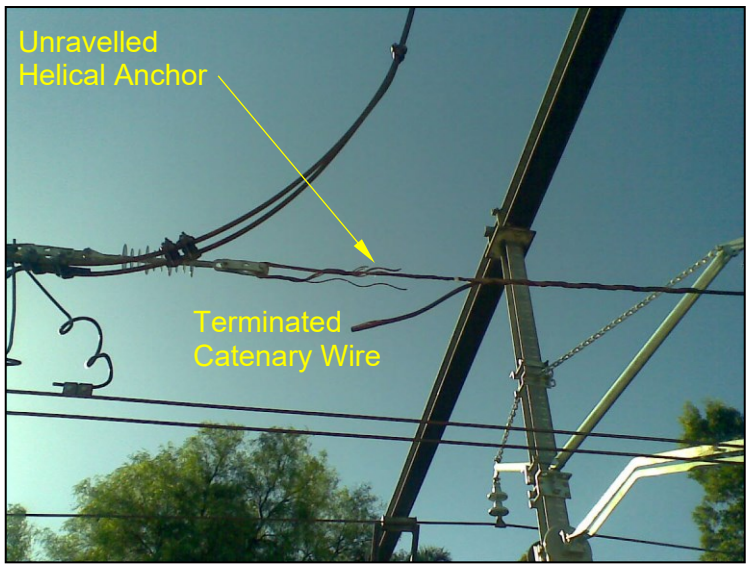


Figure 139 - Failed Catenary Helical Anchor (Liverpool)

One potentially significant down side to these items is their length, and generally the bigger the catenary size, the longer the wrap-on needs to be. The lengths are given below, e.g. for 270mm² its initial length is 1,670mm.

Nothing can be allowed to clamp around the wrap-on strands, otherwise they cannot do their gripping work, and sometimes this is a real problem, especially if a dropper needs to connect to catenary to support the contact wire in that area.

For example, see the clamp installed onto the helical anchor in *Figure 140* – the manufacturer would not guarantee their product if anything clamps around the helical anchor fitting anywhere over its installed length.

Aside:

Figure 140 demonstrates both an ignorance of proper installation, and a tolerance by others, and both attitudes should be a real concern. Unfortunately, bad habits like this can send the wrong message, that it's somehow OK to do this, when *it's absolutely not acceptable*. The best way to correct this attitude is to identify the fault and promptly fix it, then communicate it to others (along with reasons). This way, it gives less time for others to notice and mimic it.

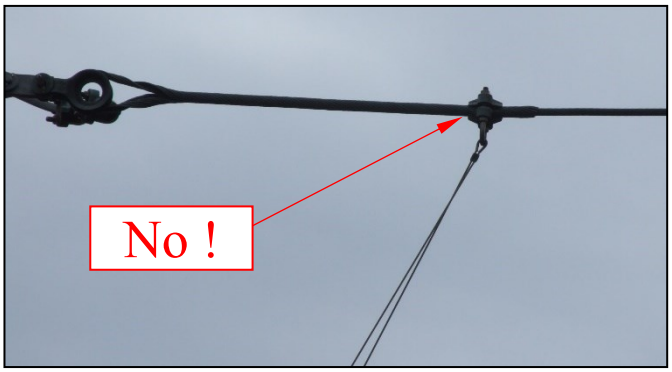


Figure 140 - Helical Anchor (wrongly installed)

The helical wrap-on fittings are:

- *165mm² catenary* – Fitting 282/1 (drawing EL 0225883) Initial length = 1,140mm.
- *270mm² catenary* – Fitting 282/2 (drawing A3/89294) Initial length = 1,670mm.
- *327mm² catenary* – Fitting 282/3 (drawing A3/89372) Initial length = 1,500mm.

Note:

There is no helical wrap-on fitting for the 510mm² catenary wire size.

Figure 141 - Helical Wrap-On being tested

FORKED COLLAR SOCKET

These fittings were approved post-2008. Refer to *Figure 142* which shows a 270mm² catenary wire being terminated to a K-Line insulator.

Figure 142 - Catenary Forked Collar Socket

They are identical in form to those used for terminating the contact wire, although the bigger the wire is, the longer the fitting needs to be.

Fortunately, they are much shorter than the equivalent wrap-on fittings described above, and can offer big benefits especially in this regard.

The catenary is fed through a special brass alloy collar with serrated teeth. Pulling the catenary back locks it against the collar inside the forked collar socket body, thus providing a strong mechanical connection as tension is applied.

These fitting are relatively light and easy to install, although I'm not sure about the policy of whether the conical wedge that grips the catenary can be reused elsewhere (or even adjusted in local position) after being tensioned.

The fittings are:

- *165mm² catenary* – Fitting 462/20 (drawing EL 0015240)
  Length = 240mm. Uses 16mm diameter stainless steel connecting pin. Note that this is the same fitting as that used for 193mm² contact wire.
- *270mm² catenary* – Fitting 462/21 (drawing EL 0558871)
  Length = 300mm. Uses 20mm diameter stainless steel connecting pin.
- *327mm² catenary* – Fitting 462/22 (drawing EL 0559348)
  Length = 300mm. Uses 20mm diameter stainless steel connecting pin.

BOLTED CLAMP ARRANGEMENT

This is a simple arrangement and one that was better suited to small conductor sizes, such as steel catenary wire and possibly 165mm² catenary. See *Figure 143* for 2 such instances.

This arrangement consisted of a series of U-bolt clamps installed on the 2 thicknesses of the overlapping wire, i.e. on the wire and on its return portion.

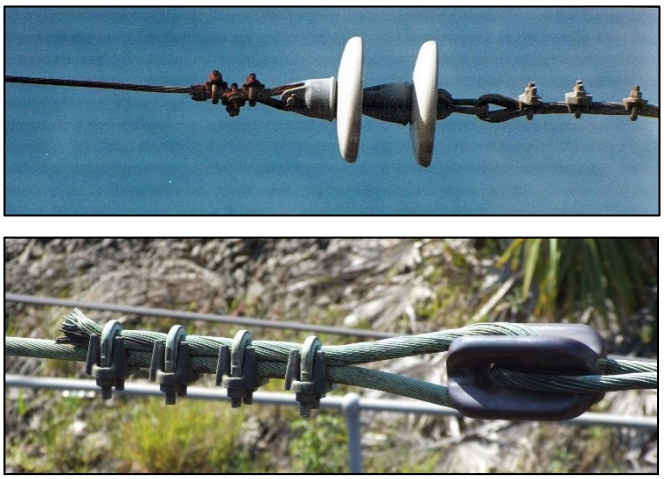


Figure 143 - Bolted Clamp Arrangements

The friction from the large number of U-bolt connections caused a reasonable overall termination for moderate tensions, although the successive distribution of tensions would unlikely be equal, causing greater stress on some strands than others.

This configuration has not been used for a long time now, because there's more sophisticated and effective equipment available, including the forked collar sockets, wrap-ons and various connectors using the wedge principle. Besides, the steel catenary is no longer to be installed.

3.1.8.5 Design Notes

CATENARY SNAIL CLAMP

In the late 1980s there were some problems experienced with the snail clamps a few years after installation on the Illawarra Electrification Project (from Waterfall to Pt Kembla). A technical note was issued on 24/8/1990, and it provided a good summary of the problem and identified the cause and solution, as detailed below.

> *"On the Waterfall to Pt Kembla Electrification Project, the method used to install catenary snail clamp termination fitting no. 281/3 resulted in broken conductor strands which required re-termination of all anchorages.*
>
> *The failure resulted from installing the fitting on tensioned wire with the clevis vertical so that the wire bends round the fitting to take up its final shape when the anchor fittings are attached to the clevis.*
>
> *This bending process overstressed the strands on the outer radius of the bend which caused the strand failure. There is approximately 19mm more length in the outer radius than the inner radius of the bend and sharing of the load between strands was not possible due to the clamping action of the U-bolts.*
>
> *The termination fitting MUST be installed on non-tensioned wire with the wire bent to the shape of the fitting, with the clevis in its final horizontal position. This results in the stress in the outer radius strands and the inner radius strands being approximately equal due to strand movement when the wire is bent to shape prior to clamping".*

It appears that the two culprits here were the extremely high catenary tension of 30kN, coupled with the method of bending the catenary wire around a radius under full tension during construction.

It highlights the need for each individual catenary strand (37 of them) to share the load in this highly tensioned conductor, otherwise overstressing can happen and fatigue in time is one likely outcome.

Once one strand snaps, the remaining strands then need to share its load, which makes matters worse, and this can accelerate the process and eventually lead to conductor breakage (which can be unpredictable, affecting the reliability of the OHW).

A consequence of this situation was the eventual edict that no more snail clamps were to be installed for catenaries under high mechanical tension.

It seems that the only snail clamps still in use are those associated with the 510mm² catenary system (Hornsby to Gosford, if this OHW system is still in service), as there is no other termination clamp substitute, and provided they are installed correctly there should be no problems. This large catenary size is also on the way out and no longer to be installed for future works (for other good reasons).

CATENARY WRAP-ON

This piece of equipment seems to be a piece of magic. It is simple but unfortunately it also appears to be fairly unforgiving if not installed correctly.

There must be no clamps installed onto the wrap-on itself, otherwise these strands cannot perform their magic of gripping the catenary wire, and the manufacturer will not guarantee his product. The wrap-on strands need to be allowed to do their work unimpeded.

Some unexpected failures of wrap-ons happened around 2010 that apparently remain unexplained by the manufacturer, even after much testing by them. This accelerated the need

to adopt an alternate catenary termination clamp, i.e. the forked collar socket (see below).

CATENARY FORKED COLLAR SOCKET

This relies on the series of small annular wedges on the inside of the collar biting into the outer strands of the catenary as the collar slides and compresses within the conical body when tensioned. Apparently, the outer strands in turn bind to the inner strand layers of the catenary for a very effective connection.

It is a simple arrangement that is relatively compact, lightweight and quite effective in terminating the high conductor tensions. Destructive tests have apparently shown that the wire snaps elsewhere before the clamp has a chance to fail.

There are no obvious problems with this device (provided you don't inadvertently trap your finger in the collar and cone).

BOLTED CLAMP ARRANGEMENT

Problems with the use of U-bolts can arise if they are not correctly installed and properly tensioned. To be effective, each clamp needs to take its fair share of the terminated load.

Corrosion over time is the other problem with this arrangement (as seen in the upper photo of *Figure 143*). The U-bolt clamps are typically made from steel, so hidden pockets of rust in particular can bring the whole arrangement down without many other signs of a looming failure.

(Note that this type of arrangement is still quite suitable for terminating the much lower tensioned cross-span situations typically found at support & registration arrangements on portals.)

3.1.8.6 Status (c. 2014)

- *Catenary snail clamps* – Not for future use (except for 510mm² catenary)
- *Catenary wrap-ons* – Not for future use
- *Catenary forked collar sockets* – Approved for future use for 165mm², 270mm² & 327mm² catenary sizes.
- *Bolted clamp arrangement* – Not for future use.

3.1.8.7 Reference

Snail clamps:

- 270mm² catenary – Fittings 281/3 & 281/8 – drawing C/73448.
- 327mm² catenary – Fitting 281/3 & 281/8 – drawing C/73448.
- 510mm² catenary – Fitting 281/2 & 281/9 – drawing C/73445.

Catenary wrap-ons:

- 165mm² catenary – Fitting 282/1 – drawing EL 0225883.
- 270mm² catenary – Fitting 282/2 – drawing A3/89294.
- 327mm² catenary – Fitting 282/3 – drawing A3/89372.

Forked collar sockets:

- 165mm² catenary – Fitting 462/20 – drawing EL 0015240.
- 270mm² catenary – Fitting 462/21 – drawing EL 0558871.
- 327mm² catenary – Fitting 462/22 – drawing EL 0559348.

Bolted clamp arrangement: N/A.

3.1.9 Catenary Splices

3.1.9.1 Description

Catenary splices are used to repair the catenary wire. They can appear at just about any location in a bay of OHW.

3.1.9.2 Function

Catenary splices provide a means of mechanically joining two pieces of catenary wire together, or otherwise repair the conductor if stranding occurs.

Like the catenary they are reconnecting, they are intended to provide good heavy-current electrical continuity with low resistance.

3.1.9.3 Typical Components

See "Configuration" below.

3.1.9.4 Configuration

Catenary splices are of several types:

- 12-Bolt Box Clamp
- Cone Splice
- Wire Clip Arrangement
- Preform Wrap-on
- Back-to-Back Snail Clamp Splice
- Back-to-Back Helical Anchor Splice
- Back-to-Back Forked Collar Socket Splice

12-Bolt Box Clamp

This very old clamp is a two-piece gunmetal casting that accepts a catenary wire into each end, and is secured with 12 bolts, as shown in *Figure 144*.

Each catenary wire passes into the centre of the clamp from opposite directions, then they are bent inside the clamp and exit from holes in opposite sides of the clamp. The catenaries are then clamped to the adjacent catenary wire further along for feeding heavy current.

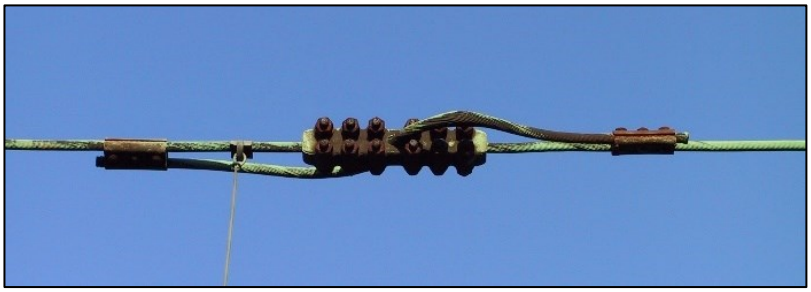


Figure 144 - A Catenary 12-Bolt Box Clamp

The box clamp itself provides the mechanical connection, while the additional feeder connections to catenary allows a good electrical connection to be made, i.e. it does not rely on any electrical connection that happens to be made inside the box.

CONE SPLICE

The cone splice relies on the wedge principle to secure the catenary wires to the splice fitting.

Referring to *Figure 145*, the end cones and locking rings are placed on each catenary wire to be joined, and a conical wedge is inserted under the outer layer of these wires.

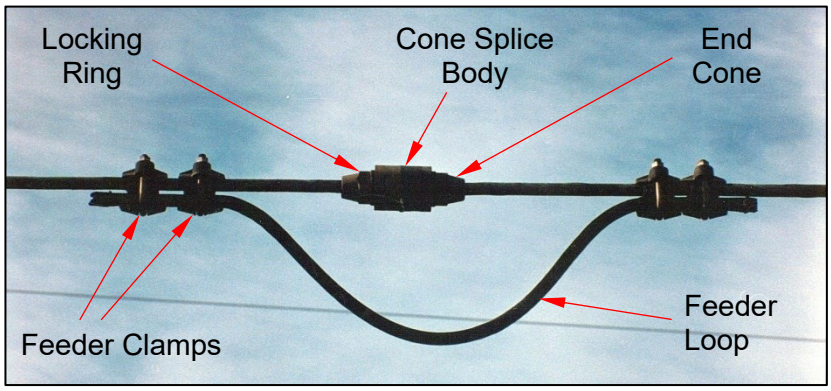


Figure 145 - Catenary Cone Splice

The end cones are drawn onto the catenary where the conical wedges have been placed under the outer layer of catenary. This wedges the outer layer of catenary strands between the conical wedge and end cone, and also wedges the catenary inner layers in the centre of the conical wedge. The end cones and body have left and right-hand threads, so when the end cones are matched to the body and the body rotated, the end cones are drawn into the splice body, pulling the conical wedges and end cones together. The locking rings are then tightened to lock the arrangement.

If the splice is installed on old catenary, a feeder loop is installed over the cone splice to conduct most of the electric current away from the splice connection itself. Apparently there had been failures of the splice arrangement itself because the old catenary strands could not be cleaned enough to reliably conduct current through the splice fitting. So, a feeding loop was installed to assure heavy current does not pose a long term problem.

WIRE CLIP ARRANGEMENT

The two catenary wires are overlapped and a number of wire U-bolt clamps are installed and clamped tight to prevent the wires from slipping through. This is a fairly primitive approach, but could be effective to a degree. See *Figure 146*.

This configuration is usually only performed on smaller diameter wires, notable steel catenary.

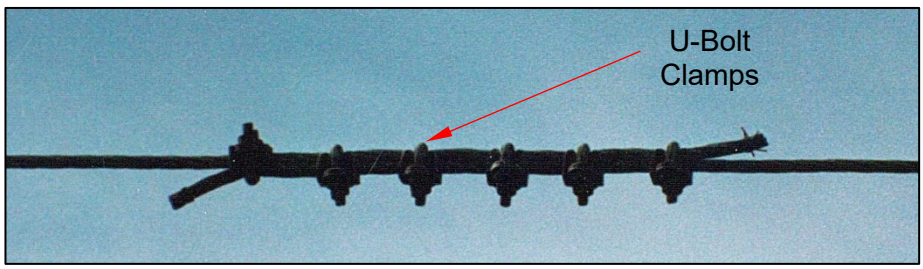


Figure 146 - Bolted Clamp arrangement (with 6 U-Bolt Clips)

Current transfers between the 2 catenaries mostly via the series of U-bolt fittings.

PREFORM WRAP-ON

I think the official term for this rather simple but effective piece of equipment is "helical in-line preformed wrap-on" (or the like), and they are made to Australian Standard AS-1154.3.

This device consists of a number of specially preformed helical strands of wire that are installed over the cut catenary wire (which is butted together). Refer to *Figure 147*. An in-field example was also shown previously in *Figure 71*.

The wrap-on must be designed for installation onto the specific catenary wire size and stranding composition being joined. Most importantly, it must have the same direction of lay as the outer layer of the catenary (which in Sydney is right-hand lay).

I understand that, for it to work as intended, the catenary needs to part before the wrap-on is applied, so that it can then firmly tighten against the catenary wire as the wire tension is applied. Refer to the manufacturer's instructions for any special preparation.

Properly installed, this used to be one of the most convenient and effective splicing arrangements available, as it seemed to provide an excellent mechanical and electrical connection.

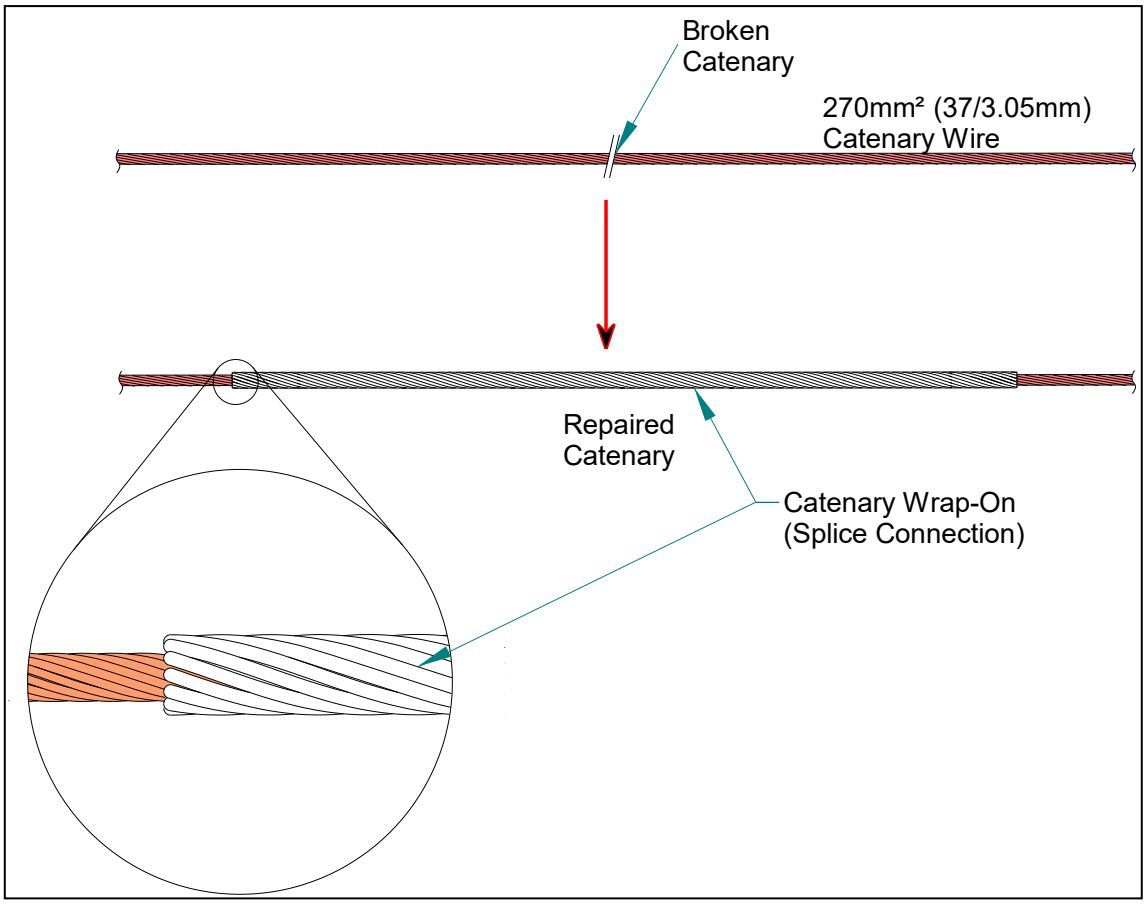


Figure 147 - Catenary Wrap-on Full Splice

BACK-TO-BACK SNAIL CLAMP SPLICE

This is a relatively common arrangement that has been used to perform the functions of a splice. It's effectively a bridged-out catenary pennant insulator arrangement. See *Figure 148*.

It has two back-to-back snail clamps (to terminate the catenary wires), and an insulator (or less commonly a mild steel link) installed between the clamps to take the in-line catenary wire tension.

Figure 148 - Snail Clamps used as a Catenary Splice

A piece of catenary wire is often used to electrically bridge across between the tails of the 2 catenaries, to carry the heavy dc current, and in the case of steel link, to try to prevent any current passing

through the stainless steel connecting pins.

In a fixed-anchored system, sometimes they would install a turnbuckle between the snail clamps as a way to directly alter the tension in the catenary wire (for whatever reason).

Back-to-back snail clamps can often be associated with a feeding loop, established to feed heavy current to the OHW. In this case, the electrical connection is made to the loop which is under no mechanical tension (however a proper feeding loop needs to include an insulator, not just a link plate).

Of course, this same approach could be used with 2 helical anchors in place of the snail clamps.

BACK-TO-BACK HELICAL ANCHOR SPLICE

This configuration is similar to the above back-to-back snail clamp splice arrangement, except it uses 2 helical anchor dead-end fittings to terminate either side of a catenary pennant insulator. *Figure 149*.

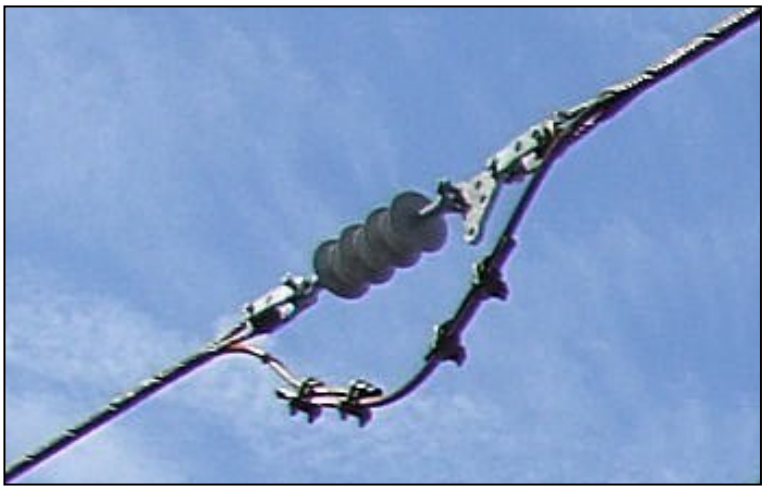


Figure 149 - Helical Anchors used as a Catenary Splice

It uses more parts than with the alternative simple "preform wrap-on" fitting, which employs the same gripping action on the catenary wires.

But like the snail clamp arrangement above, it too can be used for making a feeding connection to the out-of-tension bridge connection.

BACK-TO-BACK FORKED COLLAR SOCKET SPLICE

This configuration is similar to the above 2 *back-to-back* arrangements, except it uses 2 forked collar socket fittings to terminate the catenary wires either side of a catenary pennant insulator. The bridge is still required.

3.1.9.5 Design Notes

As detailed above, some catenary splicing has been achieved by installing a catenary pennant insulator arrangement (see next section), then bridging it out with a piece of catenary wire to allow the heavy current to flow across the arrangement.

In such situations, the insulator is called on to prevent any dc leakage currents flowing in any stainless steel catenary terminating clamps and pins which are part of the arrangement. Apparently certain types of stainless steel can be susceptible to metallurgic damage when under high mechanical stress if passing even low level dc currents through the metal, over the long term. This makes the stainless steel brittle, and care needs to be exercised to prevent such damage (thus the insulator is installed).

3.1.9.6 Status (c. 2014)

- *12 Bolt Box Clamp* – Superseded – see Preform Wrap-on below.
- *Cone splice* – Superseded – see Preform Wrap-on below.
- *Wire Clip arrangement* – Superseded – see Preform Wrap-on below.
- *Preform Wrap-on splice* – Not sure if this is still suitable for future use or whether it's been superseded, e.g. by back-to-back forked collar socket arrangement (?). Not available for 510mm² catenary.
- *Back-to-Back Snail Clamp Splice* – Snail clamps are no longer used (except for 510mm² catenary)
- *Back-to-Back Helical Anchor Splice* – Helical anchors are no longer being installed.
- *Back-to-Back Forked Collar Socket Splice* – Forked collar sockets are preferred for terminating catenary wires (except 510mm² catenary).

3.1.9.7 Reference

- *Snail Clamp* – see drawing C/73448 (fitting 281/3, 8).
- *Preform Wrap-on* – see drawing A3/89294 (fitting 282/2).
- *Back-to-Back Helical Anchor Splice* – refer to "Catenary Pennant Insulator Arrangement", drawing EL0491676.
  See also "Catenary Feeding Loop Arrangement" (for 270mm& 327mm² catenaries), drawing EL0027472.

3.1.10 Pennant Insulators

3.1.10.1 Description

A pennant insulator appears as an insulator installed in line with the catenary or contact wire, and is located within a bay of OHW – but not at anchor locations.

Catenary and contact pennant insulators usually appear together and are vertically aligned with each other. See *Figure 150*.

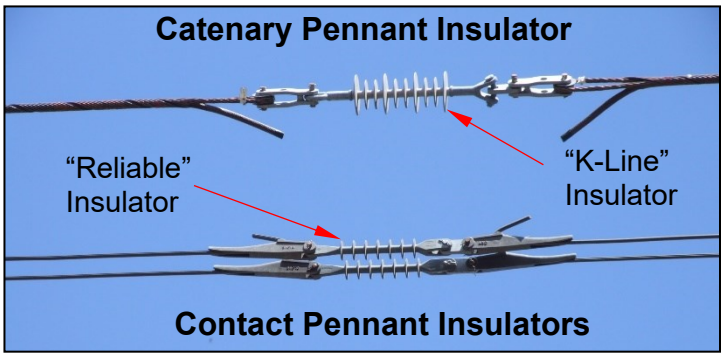


Figure 150 - Typical Pennant Insulators

3.1.10.2 Function

A pennant insulator is installed in the catenary and in the contact wire below, primarily for the purpose of electrical sectioning, i.e. allowing the OHW on one side of the insulators to be at a different electrical potential to the other side.

The catenary and contact pennant insulators need to align vertically with each other, to prevent any misunderstanding of what areas are live (with possible safety implications).

A pennant insulator can also be used to provide for feeding from an aerial feeder wire to the catenary wire.

In this way it makes the actual feeding connections to the tail portion of the catenary wire that's under no mechanical tension. So, any inadvertent high resistance joint made to the catenary tail that may result in overheating/annealing of the untensioned wire, will not cause the main catenary, that is under significant tension, to stretch and fail. This is an important strategy to improving reliability and has been Sydney's policy for many decades. In this situation, both sides can still be at different electrical sections.

Figure 151 - Pennant Insulators

Pennant insulators typically appear in the following situations:

- At *feeding overlaps* and *sectionable overlaps*, where the overlap bay has 2 parallel electrical sections, and a pennant insulator installed in the out-of-running catenary and contact, at one end or both ends of the bay, can reduce the *extent* of these different electrical sections, which has certain benefits. It is particularly necessary where the out-of-running wires cross the adjacent in-running wires when heading to anchor (for electrical clearance reasons). It can also allow the connection of aerial feeders to catenary if required for feeding overlaps. See *Figure 154* further on.
- About *midway between adjacent tracks* when OHW passes diagonally between tracks of different electrical sections, as seen in *Figure 151*.
  (*Note:* tracks that run parallel to each other normally require them to be of different electrical sections, e.g. Down Suburban, Down Main, Up Main and Up Suburban would each have different electrical section numbers.)

3.1.10.3 Typical Components

Pennant insulator components usually include:

- Two catenary or contact terminating clamps,
- A 1500V insulator or insulator pair installed in-line (capable of taking full tension),
- Associated stainless steel pins for making the mechanical connections.

3.1.10.4 Configuration

In the distant past, a pennant insulator used to typically include a 250mm (10 inch) diameter porcelain insulator rated with a tensile strength of 70kN (fitting 453/14) or 160kN (fitting 453/12). The type used depends on the worst-case operating tension of the catenary or contact wire (with 3:1 safety factor applied).

In the 1990s two new fibreglass insulators were introduced as a substitute to the porcelain insulators. These are fittings 453/16 (120kN – referred to as the "K-Line" insulator) and 453/17 (66kN – referred to as the "Reliable" insulator). Both of these are shown in *Figure 150*. Note that the maximum working tension is one-quarter of the above tension figures to allow the standards-mandated 4:1 safety factor for these fibreglass insulators.

Their main benefits over porcelain were their much reduced weight, a higher flashover voltage (meaning at anchor locations only 1 insulator was needed instead of 2 porcelain insulators in series), they were more difficult to target by vandals with rifles, and they did not have the extremely sharp edges that porcelain had when its edges were chipped off. The main disadvantage to this newer technology was that the fibreglass has very little torsional strength, so extra care was needed to not twist the insulator during installation.

Note:

Pennant insulators are *not* anchor insulators. Anchor insulators need to have a high insulation level to cope with the continual voltage stress between +1500V and earth (or -1500V), and they may also need to deal with the occasional lightning impulse.

On the other hand, pennant insulators normally spend most of the time with little or no voltage stress since both sides are at roughly the same +1500V potential. But they are occasionally called on to deal with the full 1500V stress when one side is isolated & connected to rail for short periods. So, in the old scheme, anchor insulation would comprise 2 ceramic insulators, but pennant insulation would typically need only a single ceramic insulator. (These days a single "K-Line" insulator is suitable for both anchor and pennant insulator situations.)

Refer to *Figure 152* and *Figure 153* for the current catenary and contact pennant insulator arrangements.

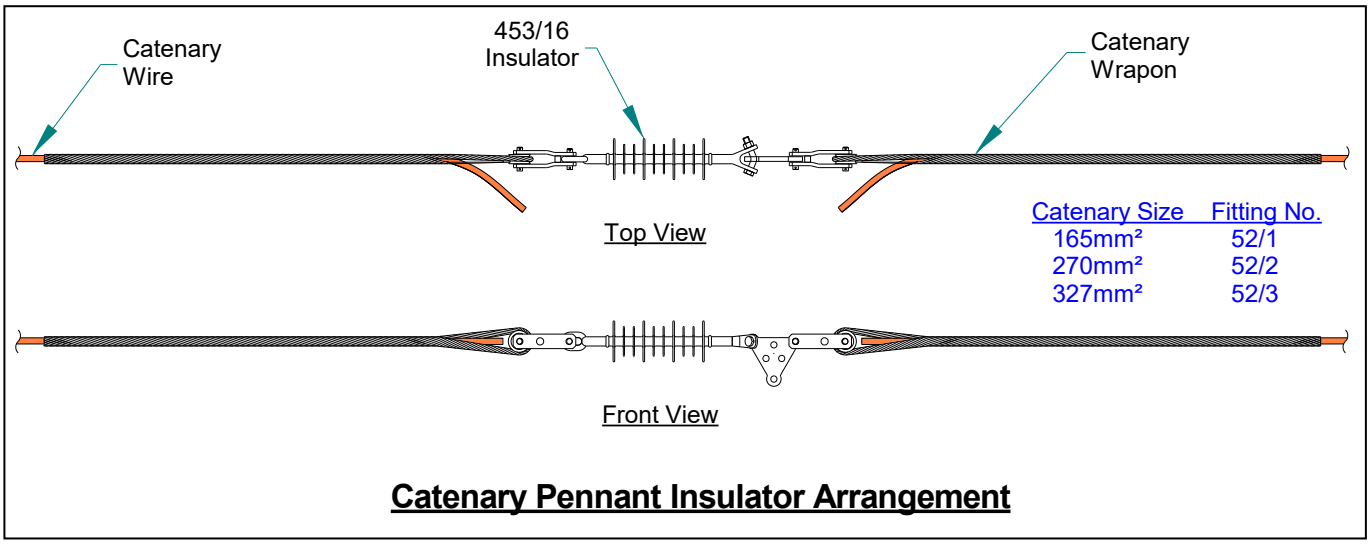


Figure 152 - Current Catenary Pennant Insulator arrangement

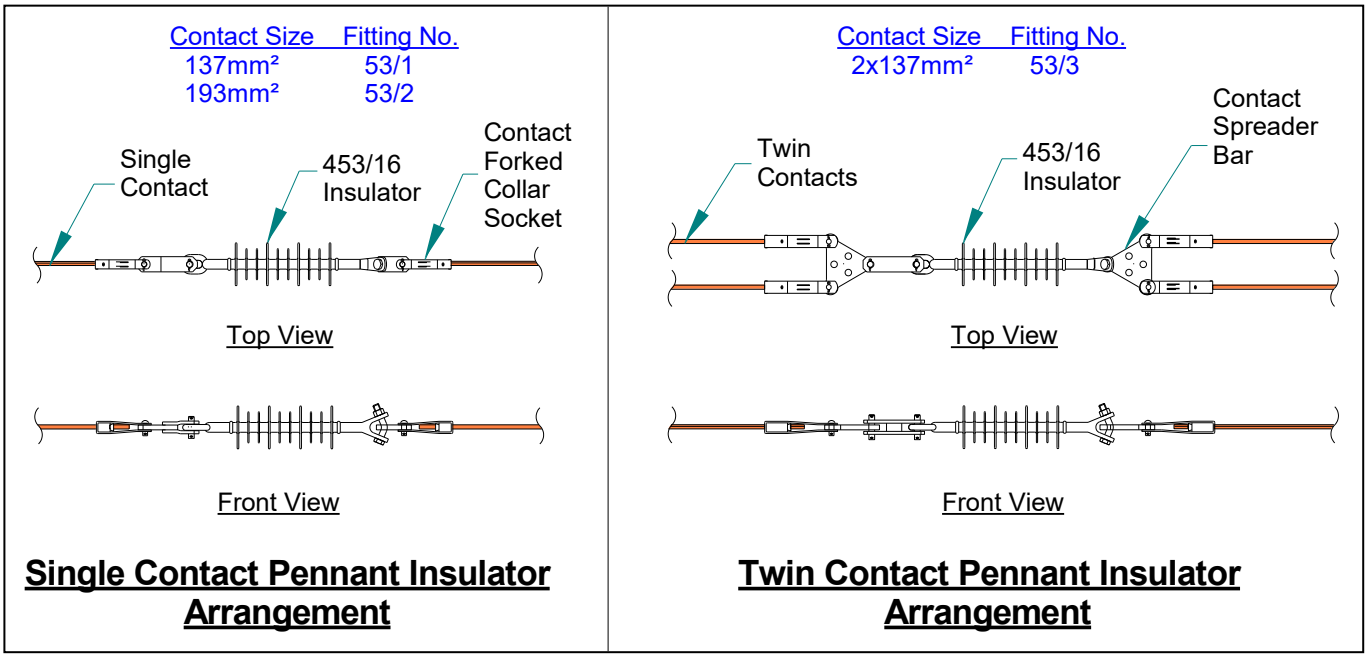


Figure 153 - Current Contact Pennant Insulator arrangement

Figure 154 shows the typical location of the pennant insulators in the out-of-running catenary and contact wires at both ends of an overlap bay (although they could be installed at just the crossing-end of the bay if required).

(For more details on anchor insulators refer to *Section 3.4*.)

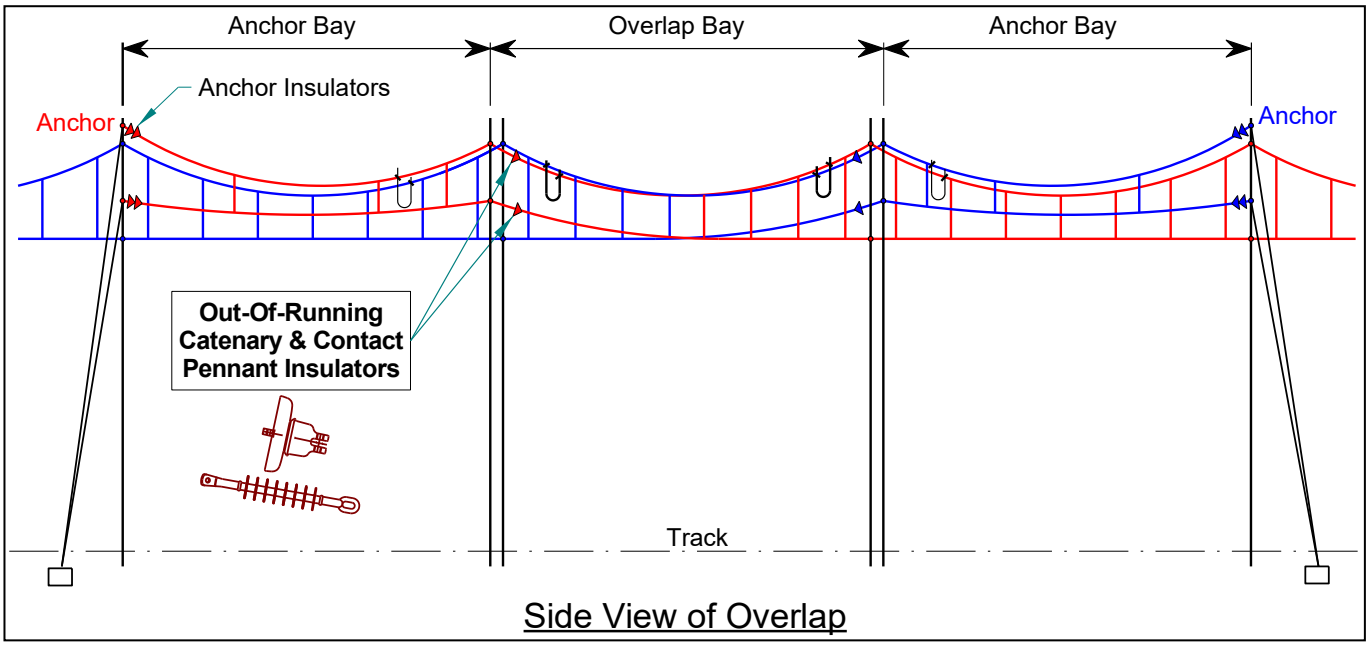


Figure 154 - Pennant Insulators in an Overlap

3.1.10.5 Design Notes

USAGE

There are a few things about the use of pennant insulators:

- Catenary and contact pennant insulators align vertically with each other.
- These days pennant insulators are used to minimise the extent of the 2 different electrical sections in a sectionable or feeding overlap. When one section is isolated & rail-connected for maintenance work, this can allow access to more of the isolated equipment without encroaching the danger zone of live equipment (overlapping of live 1500V with rail-connected OHW).

Note that, in feeding and sectionable overlaps where one wire run heading towards anchor needs to cross equipment of a different electrical section in close proximity (small electrical clearance), the electrical sections need to be made the same by installing a pennant insulator in catenary and contact wires. If there is any chance of there being any significant current in this jumper, then it needs to be a feeding jumper instead. For more information refer to *Section 3.5*.

From about the late 1970s, if the pennant insulators were required at only one end of the overlap bay, the policy was to install them at the Sydney-end, which gave some consistency to these situations. More recently, if there's the need for out-of-running pennant insulators, they're installed at both ends of the overlap bay (which, when power is removed from one electrical section, can allow access to more OHW equipment clear of the overlap bay).

INSULATORS

Several tongue & clevis ceramic insulators have been used over the years as pennant insulators as well as anchor insulators. They differ mainly in terms of their tensile strengths, skirt diameters and pin-to-pin distances. The insulators I'm more familiar with include 453/12 and 453/14, although other older ones do exist in the system.

One of the unfortunate things about these insulators was their relatively large skirt diameter (typically 254mm). When used as a contact pennant insulator, the bottom edge of the

porcelain skirt can sometimes come close to the passing pantograph just below. This is a particular concern for fixed-anchored contact wire at hot temperatures, where significant uplift can reduce the vertical clearance to the skirt.

The reduced diameter of the newer composite insulators (typically 65mm for the "Reliable" insulator or 141mm for the "K-Line") is one of the main reasons why they became so desirable to incorporate into regulated OHW systems in the 1990s (along with their much reduced weight). And the "soft" silicone edge of the insulator was a much more forgiving thing if ever struck by a pantograph (not that this is meant to ever happen).

More details of these insulators can be found in *Section 3.4*.

Fitting 453/16 is a 120kN "K-Line" insulator (Canada). It is suitable for tensions up to 30kN.

Fitting 453/17 is a 66kN "Reliable" brand insulator (USA). This is a smaller diameter insulator that's suitable for use as an out-of-running pennant insulator at an overlap. Because of its lower tensile rating, it is only suitable to terminate contact wire up to 16kN. It cannot be used by itself as an anchor insulator because of its lower flashover value, but is quite acceptable to use as a pennant insulator since both sides are normally at 1500V (i.e. no voltage stress).

3.1.10.6 Status (c. 2014)

The below 4 insulators are generally suitable, provided they will not become overloaded by the applied maximum anticipated conductor tension (with the appropriate safety factor applied to the insulator).

There may also be other restrictions – refer to the current Standards.

3.1.10.7 Reference

For specific insulators:

- Fitting 453/12 – 254mm diameter, 160kN Porcelain insulator – refer to drawing E/83542.
- Fitting 453/14 – 254mm diameter, 70kN Porcelain insulator – refer to drawing/83614.
- Fitting 453/16 – 120kN "K-Line" Fibreglass insulator – refer drawing EL 0216729.
- Fitting 453/17 – 66kN "Reliable" Fibreglass insulator – refer drawing EL 0150595.

For *Catenary* Pennant Insulator arrangements:

- Fitting 52/1 – 165mm² catenary, drawing EL0491676.
- Fitting 52/2 – 270mm² catenary, drawing EL0491676.
- Fitting 52/3 – 327mm² catenary, drawing EL0491676.

(*Note:* The above use a catenary wrap-on anchor. New arrangements are likely available for the replacement forked collar socket equivalents.)

For *Contact* Pennant Insulator arrangements:

- Fitting 53/1 – 137mm² contact, drawing EL0491677.
- Fitting 53/2 – 193mm² contact, drawing EL0491677.
- Fitting 53/3 – 2x137mm² contacts, drawing EL0491678.

3.1.11 Contact-to-Contact Feeder Jumpers

3.1.11.1 Description

Contact-to-contact feeder jumpers appear as inverted U-shaped, multi-stranded copper wire joining one contact wire to an adjacent contact wire, and typically located at a crossover.

They occur in fixed-anchored contact wire where there is no relative longitudinal contact wire movement with temperature changes.

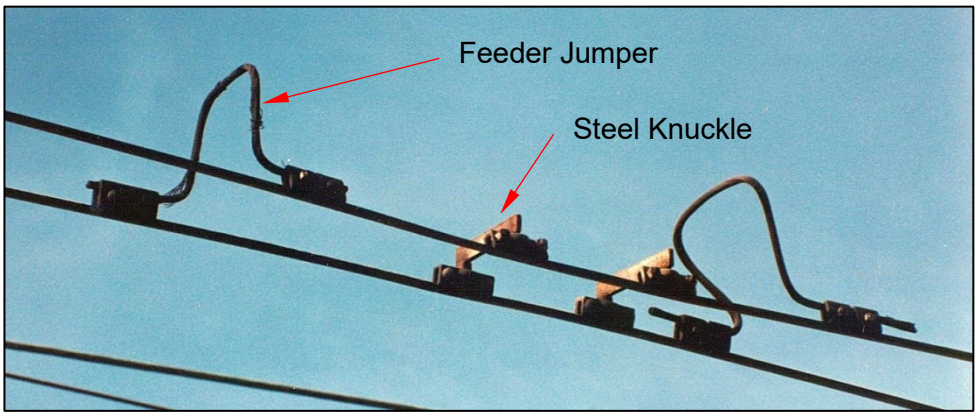


Figure 155 - Contact-to-Contact Jumper arrangement

3.1.11.2 Function

Contact-to-contact feeder jumpers enable heavy current to feed from one contact wire to an adjacent contact wire.

These jumpers are installed on both sides of a non-insulated (steel) contact knuckle, so as to minimise the amount of current feeding in the knuckle arrangement itself. This action reduces any likelihood of burning of the knuckle connections because the electric current passing through the knuckle will be much reduced. (This is particularly important in the case of steel catenaries, which should have no current feeding in the steel wire between the different wire runs, relying instead on the contact wires for supplying power to the train.)

The importance of these feeders is borne out in the fact that they are normally placed with one each side of the steel knuckle. See *Figure 155* which bears testament to this. (Note the badly formed jumper on the right-side jumper, and evidence of stranding on the left jumper.)

These jumpers are close to the action, and so need to remain well clear of the passing pantographs under all likely situations.

3.1.11.3 Typical Components

Contact-to-contact feeder jumpers typically include:

- Stranded hard-drawn copper wire (typically 90mm²), and
- Contact feeder clamps (one for each contact wire).

3.1.11.4 Configuration

Contact-to-contact feeder jumpers are made from multi-strand copper wire, usually the same type of wire as used for in-span feeders (90mm²).

They are attached to the contact wire using the same feeder clamps as for in-span feeders, e.g. fitting 56/14.

3.1.11.5 Design Notes

USE IN FIXED-ANCHORED OHW ONLY

These feeder jumpers are only suitable where there is no relative longitudinal contact wire movement. So, they are acceptable for fixed-anchored OHW, but this virtually rules out their use in regulated OHW.

Any significant longitudinal movement will distort the shape of the jumper. It could also eventually lead to fatigue on the multi-stranded copper conductor, likely at the point of connection to the contact feeder clamps.

STIFFNESS

The hard-drawn copper wire used in this arrangement must not be allowed to anneal, because it may then become soft enough to change its shape and sag into the path of pantographs below.

So, this requires that there be enough catenary feeder jumpers located nearby to help share the majority of load current without them overheating.

STEEL KNUCKLE VERSUS INSULATED KNUCKLE

The use of these potentially flexible jumpers located so close to the train's pantographs poses a risk. The strategy of using a steel knuckle that requires these jumpers be installed each side, must have been seen as more effective and/or reliable than installing a permali beam insulated knuckle (with its own ongoing maintenance requirements), and relying instead on the catenary feeder jumpers to pass heavy current between the 2 runs of wire.

The jumpers are located on both sides of a steel knuckle to minimise the amount of current feeding through the knuckle itself.

More importantly, it's the swivel nature of the steel knuckle that causes the concern, as any moving part that also carries any significant dc current is also susceptible to arcing and current erosion at the moving connection/s. The swivel action of the knuckle installed on contact wires is required to prevent fatigue as the numerous pantograph passages push one contact and its clamp upwards and cause it to rotate relative to the adjacent contact wire before coming back down. This movement is most pronounced under hot conditions with low contact tension.

This is a similar adverse situation faced with the upper and lower loops of a dropper arrangement, and it's the reason why insulation was eventually introduced into these dropper arrangements.

As mentioned above, the ideal situation would probably be to use an insulated knuckle, but these have their own particular problems.

However, in many cases of this knuckle arrangement, the catenary is made from steel which should not be used to conduct heavy current, and so the contact-to-contact feeders must have been the only logical choice.

3.1.11.6 Status (c. 2014)

The current practice is to use contact-to-contact feeder jumpers in fixed-anchored OHW adjacent to any steel knuckles, although the need for such is rare these days.

3.1.11.7 Reference

See *Figure 155*.

3.1.12 Catenary Feeder & Potential Jumpers

3.1.12.1 Description

The standard catenary "feeder jumper" ("FJ") and "potential jumper" ("PJ") both appear these days as a vertical U-shaped copper wire installed between two catenaries, at a location where they come close together (usually about 300mm horizontally apart). See *Figure 156* for instance.

Feeder jumpers are typically installed at overlaps, crossovers and turnouts to sidings, etc. Potential jumpers are typically only found at overlaps on the pennant wire going to anchor.

The connection to the catenaries should use cross clamps, so the jumper wire is set at 90° to the catenary.

Feeder jumper arrangements since the late 1980s include the connection of in-span feeders onto the jumper wire for feeding current down to the contact wires below.

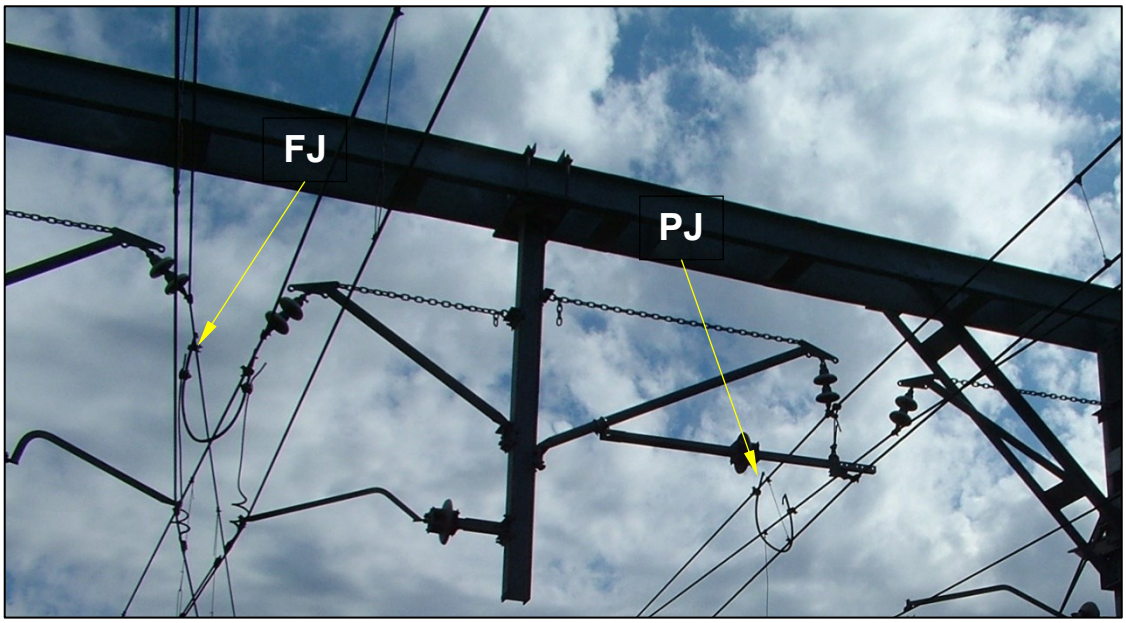


Figure 156 - Feeder Jumper ("FJ") & Potential Jumper ("PJ") arrangements

An older style of jumper arrangement consisted of an almost horizontal U-shaped wire installed with parallel clamps to the catenaries. See *Figure 157*.

This type is restricted to use in fixed-anchored OHW where there is no relative horizontal wire movement and very little relative vertical wire movement with temperature.

It has been superseded for future use by the vertical U-shaped arrangement (above) due to fatigue problems experienced over the years.

An "Auxiliary Feeder Jumper" ("AFJ") is a special type of catenary feeder jumper that

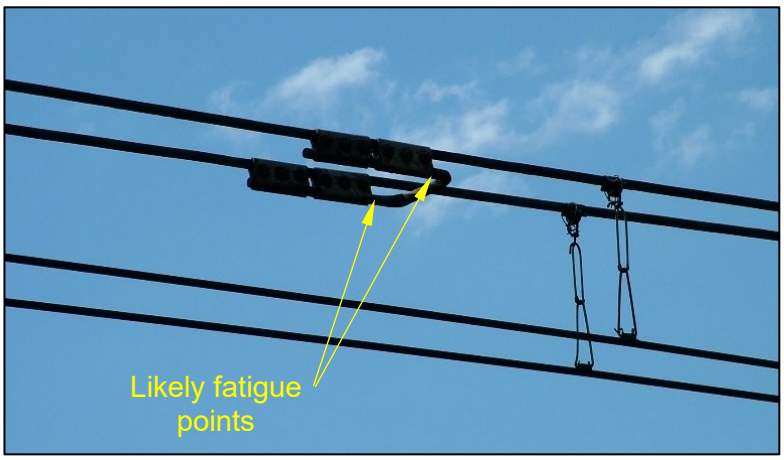


Figure 157 - Older horizontal Feeder Jumper (fatigue problem)

connects an auxiliary catenary wire to its adjacent catenary wire at a similar height. They are typically installed every few bays along the auxiliary feeder route (*Figure 163* further on).

3.1.12.2 Function

Catenary feeder jumpers – FJs provide a means of passing heavy electric current from one catenary wire to an adjacent catenary. So, feeding train current to the next wire run relies on a minimum of 2 of these short copper connections (refer to current standards as to the number required, which depends on the bay lengths).
Recent changes have included connections to the contact wires as well, using in-span feeders from the untensioned "U" jumper wire.

Catenary potential jumpers – PJs provide a means of making an adjacent catenary the same electrical potential. This can help ensure that there are no "floating" sections of OHW conductors (a requirement of the standards which has been in place for a long time).
These jumpers are not intended to take heavy current, otherwise they would need to be upgraded to feeder jumpers. So, care needs to be exercised if there's an additional jumper installed somewhere else that could then cause current to pass through the installed potential jumper!

In a regulated OHW system, a jumper performs its functions whilst also allowing for a fairly large amount of relative longitudinal wire movement in both directions (with cold and hot temperature extremes).

3.1.12.3 Typical Components

A *feeder jumper* consists of a length of feeder wire (the jumper), and 2 matching feeder cross-clamps (one for each catenary wire being connected). Since about 1990, the feeder jumpers also include standard in-span feeders connected from the U-shaped jumper wire down to each of the associated contact wires of the 2 wire runs. So, a single catenary / twin contact connection to an adjacent single catenary / single contact system, would require 3 in-span feeders.

A *potential jumper* normally uses the smallest wire size for making the electrical connection, i.e. 90mm² hard-drawn bare copper, with appropriately sized cross-clamps to connect to the 2 catenaries. There must be no significant current flowing through this wire.

3.1.12.4 Configuration

Catenary feeder jumpers – the jumper wire itself is generally a piece of catenary wire normally of the same cross-sectional area as the larger of the 2 catenary wires being electrically connected. (Note that, because this jumper wire is under no tension, in theory it may be possible to use the size of the smaller of the 2 catenaries.)

Catenary potential jumpers – the jumper wire generally uses a lighter gauge wire, which is normally 90mm² (the same as used for in-span feeder wires). Two catenary cross-clamps are also needed that match each catenary to the jumper wire.

Both types of jumpers are bent to a U-shape to suit the catenary spacing and to cope with a certain amount of catenary wire movement, without either restricting this movement or causing a fatigue problem. This latter part is relevant for the wire movement in regulated tension OHW.

The jumpers are usually installed where the 2 catenary wires are about 300mm apart, which gives adequate mechanical clearance so that the "U" shaped wire doesn't get caught up with itself or associated hardware.

Where used in regulated tension overlaps, the depth from catenaries to the bottom of the "U" should be at least 800mm, to cater for the extreme longitudinal wire movement with temperature. See *Section 3.1.12.5*, *Depth of Jumper*. Bear in mind that both catenaries usually – but not always – move in opposite directions with temperature (relative to a common position at the design temperature).

To achieve this 800m depth, the total length of feeder wire should be about 1,900mm.

This depth is needed to provide unimpeded wire movement with temperature extremes, and to prevent any fatigue of the feeder/potential jumper wire at the clamp connection points to the catenaries.

Current practice is to install in-span feeders at each catenary feeder jumper to promote more effective feeding down to the contact wires as well. This is needed because of the far greater currents demanded from the OHW by trains nowadays.

It is extremely important to clean the catenary wire before making the clamp connection, and to firmly tighten the U-bolts on the clamp. This helps to ensure a good low resistance clamp connection from catenary to the jumper wire, which is needed to avoid a hot spot developing with heavy currents. Any high resistance joint here may begin to anneal the catenary (under tension), and jeopardise the reliability of the OHW.

An ***auxiliary feeder jumper*** (AFJ), which connects an auxiliary feeder to catenary, usually takes the same form as the catenary-to-catenary feeder jumper described above, although the horizontal connecting distance can be up to 2m or even more (see *Figure 163* for instance).

Sometimes an AFJ installed in the tight confines of a tunnel can require a more unusual configuration that prevents the possibility of this wire from coming too close to the tunnel ceiling or to passing pantographs – there's not a lot of room up there!

3.1.12.5 Design Notes

DEPTH OF JUMPER

For regulated OHW, each feeder or potential jumper needs to be "U" shaped and have a depth of at least 800mm from catenary attachment clamps to the bottom of the "U". That is unless Design has confirmed that a shorter length is more suitable at a particular place (for instance, due to shorter wire runs from fixed anchor or fixed mid-point to the FJ or PJ).

Figure 158 shows the feeder jumper (with any in-span feeders omitted for clarity).

I don't know how many times I've seen feeder or potential jumpers with inadequate vertical depth over the years (a few are even shown in photos in this document).

Some jumpers have been installed with a circular shape instead of a deep "U", making it hard to confirm that there's enough wire length in the arrangement for it to perform correctly under temperature extremes.

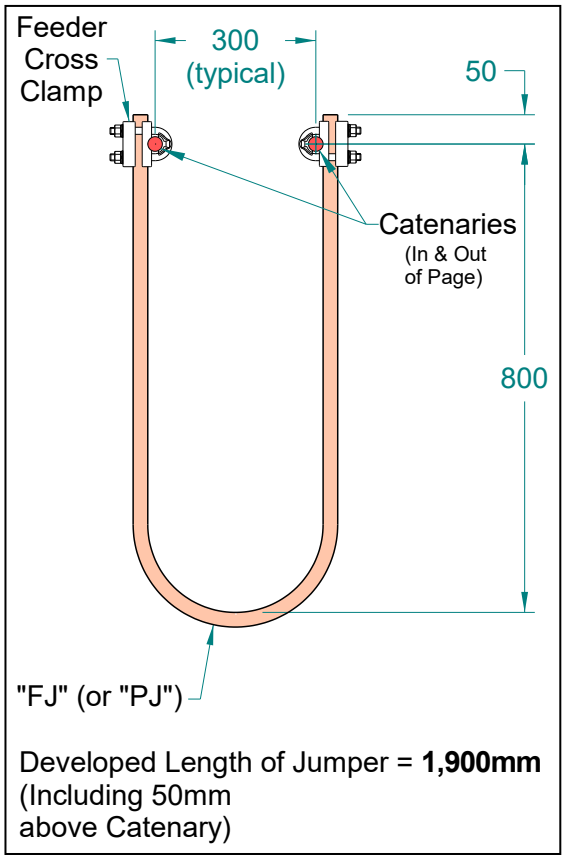


Figure 158 - Standard Jumper depth

This 800mm standard depth ensures that there should be no future problems if the 2 connected tension lengths at an overlap are both the full length of about 1,000m.

Figure 159 is my attempt to show the 2 extremes of jumper movement due to *cold* and *hot* temperatures, with each wire catenary run 1,000m at that jumper location, e.g. at an overlap with tension regulators at both anchor locations.

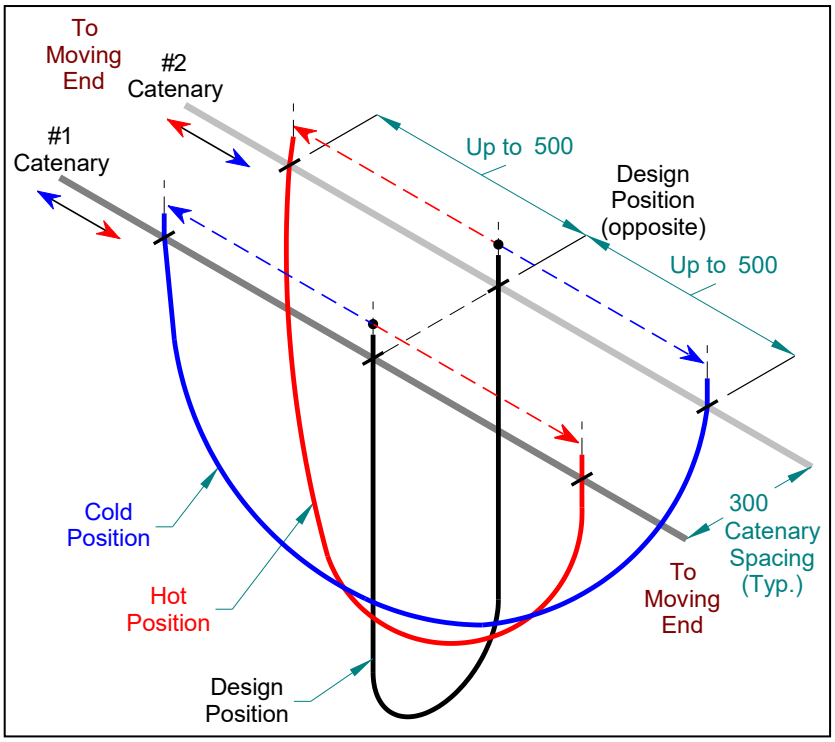


Figure 159 - Jumper movement in Regulated OHW

Since these catenary wires move in opposite directions with temperature (centred about some design position, e.g. at 21°C or better still 25°C), the jumpers need a good amount of slack in order to cope with these temperature extremes without restricting catenary movement (if the jumper becomes bar tight), or causing fatigue in time (at the clamp connections).

It is also desirable that the stranded feeder wire not "birdcage" in the process, which could happen in these situations.

The developed length of the jumper wire itself needs to be about 1,900mm (including 50mm above centre of catenaries to allow for installation of feeder cross-clamps).

The installation of the jumper wire and both cross-clamps should ideally be oriented to avoid clashing (as shown in *Figure 158*), just in case the catenaries come close to each other (for whatever reason).

Lastly, a note in the "*Liverpool – Campbelltown – Glenlee Electrification*" report c.1968 by A.R. Hamilton (Construction Engineer), regarding (270mm²) feeder jumpers, mentioned:

> *Tests were carried out which proved that, provided a sufficiently long jumper loop was installed, no deterioration of the stranding occurred, even after test operations produced 40-50 years of normal usage under the maximum conditions of movement. A loop or "U" type jumper 3ft to 4ft deep satisfied the requirements. It is interesting to note that tests showed when the depth of the loop or "U" was reduced to 2ft (600mm) the strands commenced to fail after 1860 movement cycles which would correspond to only 2½ years of normal working.*

JUMPER INSTALLATION OFFSET

Figure 161 is a table I put together (draft only) to help construction & maintenance staff to set the *correct offset* between the cross-clamps of the 2 catenaries joined by the jumper, which is a function of *wire temperature*. In this situation, it is necessary to know the 2 distances between the jumper and the fixed anchors (or fixed mid-point anchors) of each of the 2 runs being connected. (Ideally the required single "Combined Distance" value should be documented by design on the OHW layout, for reference by construction and later by maintenance, when looking up this table – then they only need to know the temperature on the day.)

I'm not sure if this table ever made it into the standards (post my retirement) or whether it was too much information or otherwise too difficult to read. But there needed to be something to guide staff on how to install the clamps at the correct offset such that, when the wire temperature is eventually at the design temperature, these clamps are directly opposite each other. This optimised the position of jumpers for the full range of catenary wire movements. (*Note:* Design temperature assumed to be 25°C for closer to equal hot and cold excursions and a better outcome, per *Section 3.1.0.5*, *Adopting a Higher Design Temperature*.)

Of course, the simplest alternative is to install the jumpers on a day that is at the design temperature. Or during maintenance, wait for a cloudy 25°C day and check that all jumpers have their clamps directly opposite each other (no offset).

Example:

> *Figure 161* shows that 2 tension lengths of 1,000m each, electrically connected at a common overlap with feeder jumpers, will have 1,020mm relative catenary wire movement in one direction when cold, and 1,190mm relative catenary wire movement in the opposite direction when hot (based on a 25°C design temperature).

If a feeder jumper has 800mm depth from catenary attachments, then this wire length between catenary clamps is approximately 800 + 800 + 300 (gap between parallel wires) = 1,900mm.

In this example it shows that, if a jumper was installed here, then its "U" shape will tend to straighten under each of the extremes of temperature, but especially when hot.

This is the reason why the 800m minimum depth from catenary clamps is required. If the depth was too short it would be straightened out and pulled bar tight, bringing the catenaries together and stifling any further movement of the catenaries, which is no good for several reasons.

See *Figure 160* for an example of a *badly set* potential jumper. This situation shows a regulated twin 165mm² catenary system interfacing the same system. This photo would not have been taken under extreme temperatures, so it will likely get much worse, with the PJ wire getting even tighter than the bar-tight feeder wire that's shown. This will cause the catenary pairs to come together (out of alignment) and will also guarantee fatigue of the stranded wire at the clamps in a very short space of time! It's also obvious there's nowhere near the required 800mm depth to the potential jumper (which is the problem).

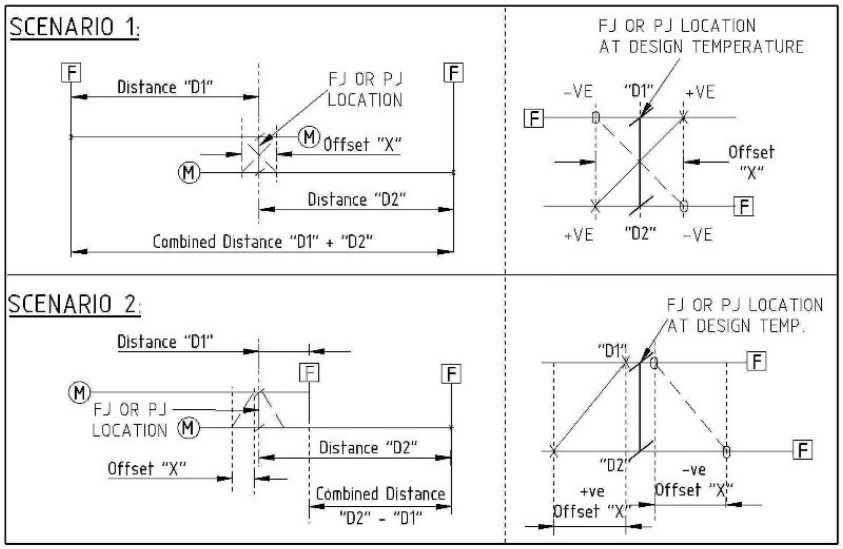
Figure 160 - Upward view of a badly installed PJ in Twin Catenary OHW

On the other hand, the depth of the jumper should not be so much as to come too close to the in-running contact wire/s below, as this may clash with an uplifted pantograph, so this needs to be taken into account during the site-specific design and/or construction.

Where the depth of the vertical jumper is an issue, an alternate arrangement needs to be designed to suit the situation. For example, the limited vertical space inside tunnels for the OHW almost mandates a more horizontal jumper configuration, but this would normally be fixed-anchored OHW which makes it is easier to get a reliable outcome.

TEMP. (°C)	COMBINED DISTANCE FROM FIXED ANCHORS "D" (m)																																												
	100	150	200	250	300	350	400	450	500	550	600	650	700	750	800	850	900	950	1,000	1,050	1,100	1,150	1,200	1,250	1,300	1,350	1,400	1,450	1,500	1,550	1,600	1,650	1,700	1,750	1,800	1,850	1,900#	1,950#	2,000#
	RELATIVE OFFSET "X" (mm)																																												
-5	-50	-80	-100	-130	-150	-180	-200	-230	-260	-280	-310	-330	-360	-380	-410	-430	-460	-480	-510	-540	-560	-590	-610	-640	-660	-690	-710	-740	-770	-790	-820	-840	-870	-890	-920	-940	-970	-990	-1,020
0	-40	-60	-90	-110	-130	-150	-170	-190	-210	-230	-260	-280	-300	-320	-340	-360	-380	-400	-430	-450	-470	-490	-510	-530	-550	-570	-600	-620	-640	-660	-680	-700	-720	-740	-770	-790	-810	-830	-850
5	-30	-50	-70	-90	-100	-120	-140	-150	-170	-190	-200	-220	-240	-260	-270	-290	-310	-320	-340	-360	-370	-390	-410	-430	-440	-460	-480	-490	-510	-530	-540	-560	-580	-600	-610	-630	-650	-660	-680
10	-30	-40	-50	-60	-80	-90	-100	-110	-130	-140	-150	-170	-180	-190	-200	-220	-230	-240	-260	-270	-280	-290	-310	-320	-330	-340	-360	-370	-380	-400	-410	-450	-430	-450	-460	-470	-480	-500	-510
15	-20	-30	-30	-40	-50	-60	-70	-80	-90	-90	-100	-110	-120	-130	-140	-140	-150	-160	-170	-180	-190	-200	-200	-210	-220	-230	-240	-250	-260	-260	-270	-280	-290	-300	-310	-310	-320	-330	-340
20	-10	-10	-20	-20	-30	-30	-30	-40	-40	-50	-50	-60	-60	-60	-70	-70	-80	-80	-90	-90	-90	-100	-100	-110	-110	-110	-120	-120	-130	-130	-140	-140	-140	-150	-150	-160	-160	-170	-170
25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30	10	10	20	20	30	30	30	40	40	50	50	60	60	60	70	70	80	80	90	90	90	100	100	110	110	110	120	120	130	130	140	140	140	150	150	160	160	170	170
35	20	30	30	40	50	60	70	80	90	90	100	110	120	130	140	140	150	160	170	180	190	200	200	210	220	230	240	250	260	260	270	280	290	300	310	310	320	330	340
40	30	40	50	60	80	90	100	110	130	140	150	170	180	190	200	220	230	240	260	270	280	290	310	320	330	340	360	370	380	400	410	420	430	450	460	470	480	500	510
45	30	50	70	90	100	120	140	150	170	190	200	220	240	260	270	290	310	320	340	360	370	390	410	430	440	460	480	490	510	530	540	560	580	600	610	630	650	660	680
50	40	60	90	110	130	150	170	190	210	230	260	280	300	320	340	360	380	400	430	450	470	490	510	530	550	570	600	620	540	660	680	700	720	740	770	790	810	830	850
55	50	80	100	130	150	180	200	230	260	280	310	330	360	380	410	430	460	480	510	540	560	590	610	640	660	690	710	740	770	790	820	840	870	890	920	940	970	990	1,020
60	60	90	120	150	180	210	240	270	300	330	360	390	420	450	480	510	540	570	600	620	650	680	710	740	770	800	830	860	890	920	950	980	1,010	1,040	1,070	1,100	1,130	1,160	1,190

#SEE NOTE 7



SITUATION PLAN VIEWS

SIGN CONVENTION
NOTE 3

DESIGN TEMPERATURE (°C):	25
ALPHA (PER °C):	17 x 10^{-6}

LEGEND

F — LOCATION OF FIXED ANCHOR OR FIXED MID-POINT

M — MOVING ANCHOR (TENSION REGULATOR)

FJ = FEEDER JUMPER

PJ = POTENTIAL JUMPER

NOTES:

1. THIS CHART IS APPLICABLE TO REGULATED OHW ONLY. IT SHOWS THE AMOUNT OF CATENARY WIRE ELONGATION ("X") WITH TEMPERATURE, AS A FUNCTION OF DISTANCE ("D") FROM THE FIXED ANCHOR OR FIXED MID-POINT.
   NUMBERS SHOWN ARE ROUNDED TO THE NEAREST 10mm.
2. AT DESIGN TEMPERATURE THE 2 FJ OR PJ CLAMPS ON THE 2 CATENARIES ARE TO BE IN LINE WITH EACH OTHER, REGARDLESS OF DISTANCE TO FIXED ANCHOR.
   AT OTHER TEMPERATURES APPLY THE RELATIVE OFFSET "X" AS SHOWN IN TABLE (WITHIN A TOLERANCE OF 50mm).
3. SIGN CONVENTION A POSITIVE "X" VALUE PLACES THE CATENARY REGISTRATION CONNECTION FURTHER AWAY FROM THE FIXED ANCHOR.
   IN SCENARIO 2, THE POSITIVE "X" VALUE IS APPLIED TO THE LONGER OF THE 2 CATENARY WIRE LENGHTS ("D2" AS SHOWN).
4. "COMBINED DISTANCE" IS TAKEN AS THE DISTANCE BETWEEN THE TWO FIXED ANCHOR LOCATIONS OF THE TWO CATENARIES ON WHICH THE FJ OR PJ IS ATTACHED
5. THIS CHART IS TO BE USED BY CONSTRUCTION STAFF TO SET THE CORRECT POSITION OF THE FJ OR PJ ATTACHMENT ON THE CATENARY WIRE, WHICH MUST BE RELATED TO THE TEMPERATURE AND SPECIFIC DISTANCE FROM THE FIXED ANCHOR.
6. THE CHART IS ALSO TO BE USED BY MAINTENANCE STAFF TO PERIODICALLY CHECK AND/OR RESET THE FJ OR PJ POSITION.
7. TYPICAL MAXIMUM DISTANCE OF OHW RUN FROM MOVING ANCHOR TO FIXED ANCHOR OR FIXED MID-POINT IS 1,000m.

Figure 161 - Feeder & Potential Jumper setup (*DRAFT only*)

NUMBER OF JUMPERS

The number of feeder jumpers installed in parallel is important for sharing the current, especially considering the extremely large current loads on the system now.

Where needed in an overlap, a feeder jumper is usually required at each end of the overlap bay. However, there may situations where more than just 2 are needed – refer to the site-specific design drawing for any such requirement.

Turnouts (including at crossovers) should also require a pair of feeder jumpers to be installed several metres apart – ideally one on each side of the actual crossing point, but located away from the forking-in points.

The danger of having just 1 Feeder Jumper is that it any loose connections may eventually cause it to act more like a fuse and become open circuit, stopping trains. Thus the need for at least 2 FJs in parallel for some redundancy and to help share the current burden.

CONNECTION OF IN-SPAN FEEDERS

In order to get a more effective distribution of heavy currents from one OHW system to the next, feeder jumpers require in-span feeders to be connected, providing an immediate feed down to the contact wire/s. This requirement was put into the standards in the late 1980s, as shown on the various standard arrangement drawings (viz. EL0004637 & 4638).

Connection of in-span feeders is made to the untensioned "U"-shaped *feeder jumper* (FJ) only. In this way, if the jumper wire gets hot or even begins to anneal, this is unlikely to cause any immediate harm to the system.

JUMPERS INSTALLED ON CATENARY IN TENSION

Feeding current from a switch, substation or sectioning hut requires the connection of the aerial feeder wires to be made to the catenary wire at a point where the catenary is under no mechanical tension. This means connecting to a feeding loop or to the tail of the catenary at its termination point. In this way, any chance of annealing this portion of the wire due to a high temperature rise at a resistive connection will not affect the tension in the catenary wire.

So why are feeder jumpers allowed to make a connection to the tensioned catenary directly?

It seems that this situation is acceptable provided there are at least 2 Feeder Jumpers installed to the OHW. This spreads the current burden carried by each, which in turn lessens the likelihood of localised overheating and annealing the tensioned catenary wire. It also provides a level of redundancy should one jumper fail until noticed and corrected.

It's really important to make sure the catenary wire is cleaned properly before installing the feeder cross-clamps, to minimise this resistive connection.

If there's any doubt, a good insurance policy is to just add another feeder jumper, as shown in *Figure 162*. This shows a new twin contact system being installed next to an old single contact system, with 2 lots of FJs connecting to the old catenary wire, just to play it safe (although they should ideally have been spaced further apart from each other to avoid any clash of fittings).

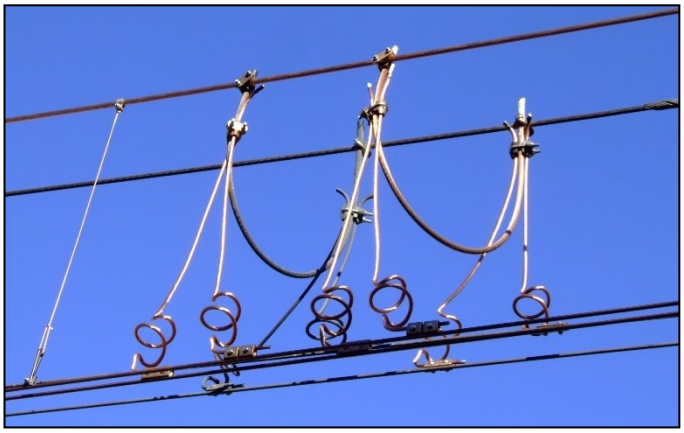


Figure 162 - Feeder Jumpers

HORIZONTAL JUMPERS

In the older OHW systems, sometimes the FJ or PJ was made with the loop being horizontal. See *Figure 157*. Unfortunately, this configuration was notoriously unreliable, due to fatigue over time at the jumper connections to the catenaries. This horizontal configuration is no longer used, and is totally inappropriate for regulated OHW anyway.

It is my understanding that these jumpers used to fatigue at the connection point of the feeder wire to the clamps. Apparently, this can occur if the catenaries lift and lower by different amounts with respect to each other. This can be due to the numerous uplifting pantographs each day and/or the differential change in catenary sag with temperature, on a daily basis. This causes the wire to bend slightly each way at the clamps, and eventually the strands begin to snap due to the consequent fatigue.

PARALLELED OHW TO REDUCE RESISTANCE

There have been overlap situations where 2 runs of OHW remain in parallel for distances greater than 100m due to certain constraints. An example is where an overlap has been formed through a station but the anchors needed to be located beyond both ends of the station (a few hundred metres apart).

Where practical, installing feeder jumpers at both extreme ends of these paralleled wires can be beneficial by helping to reduce the overall electrical resistance of the circuit. In turn, this can help to reduce the power losses in the OHW over time, particularly with such huge currents now being drawn by all trains. It may seem trivial, but every little bit can help.

Doing this makes the extra copper (catenary and contact wires) that were installed for other practical reasons, actually add some value to the situation, by forcing these lengths to share current that they would otherwise not carry, i.e. make them work as conductors of electricity!

Unfortunately, this approach is probably overlooked in most design/construction works, but it can be a way of improving the energy efficiency of the OHW system that bit extra, with very little initial outlay (i.e. relocate the feeder jumpers to the extreme ends of overlapping wires).

Of course, this is all provided both parallel runs are of the same electrical sections.

AUXILIARY FEEDER JUMPERS

Figure 163 shows a situation where the feeder jumper wire from A/F to main catenary is very long and bent in an arc shape, whilst being located very close to a cantilever pipe. The extra length of the jumper means it looks loose and is less well controlled – its position can be more influenced by wind (especially gusting wind).

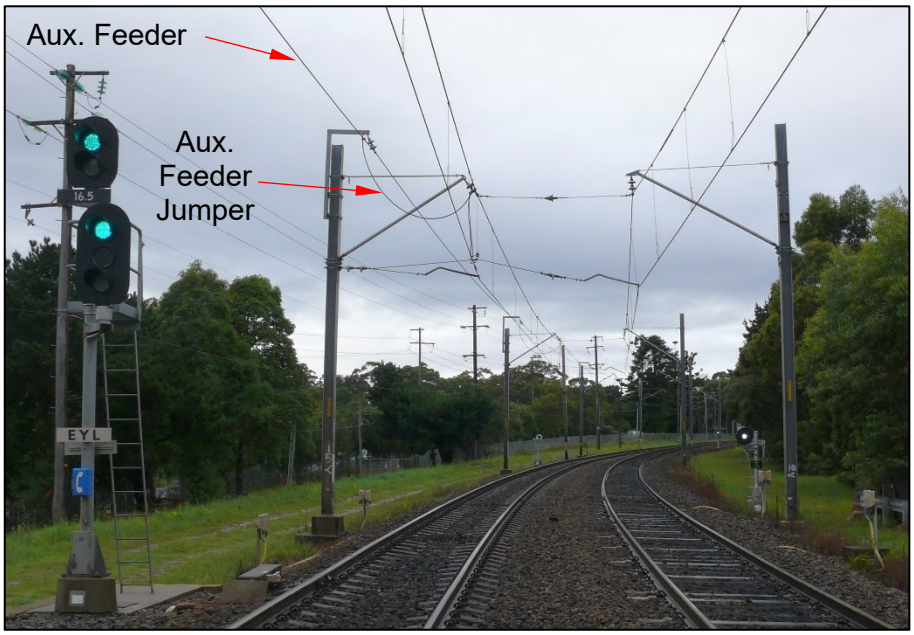


Figure 163 - Auxiliary Feeder Jumper to main OHW

So, seeing this situation can start to ring alarm bells (even though it may indeed have suitable clearances).

Probably a better outcome would result if the feeder jumper had much less sag, and it was located further away from the cantilever.

The point I'm trying to make is to emphasise the importance of designing and building something that not only is correct, but it actually looks correct, so as to avoid people asking if it's been checked out – time and again (and by different people)!

KEEP THE JUMPER ARRANGEMENT SIMPLE

It's most important that any feeder or potential jumper arrangement be installed as per design, and that it's immediately obvious how the jumper works at feeding or keeping the same electrical potential between adjacent catenary wires.

Figure 52 (further back) is a photo of an awkward potential jumper arrangement that was installed in new OHW near the end of a weekend closedown.

I don't understand how anyone could easily comprehend what this configuration was trying to achieve! And there's plenty of opportunity for wires to rub against each other, causing mechanical wear of outer strands. Or clashing/snagging of the various clamps, when the catenary and contact wires move longitudinally with temperature in this regulated OHW system. All of these things can vastly reduce the life of this jumper and ultimately cause interruption to train services if one of the main wires snaps.

The installer may have understood what he/she was trying to achieve, but subsequent regular patrols of the OHW into the future will likely baffle those involved, and slow them down each time they come across this arrangement and try to figure it out. And closely examine for signs of damage.

After pointing out the problem with this particular situation, I understand it was corrected to the standard arrangement.

In summary – keep it simple.

3.1.12.6 Status (c. 2014)

The vertical "U" shaped feeder and potential jumpers (using cross-clamps to make the catenary connections) are the standard arrangement.

The older horizontal catenary feeder jumpers (with parallel clamps) were only suitable for use in a fixed-anchored OHW system and with shallow system depth. They are no longer installed as such.

Variants are available for use inside tunnels, where there is insufficient space to install the vertical "U" shaped jumpers.

3.1.12.7 Reference

- Standard arrangement – see drawing D/88173 sheets 1 & 2 (EL0004637 & 4638).

3.1.13 Contact Wear Strips

3.1.13.1 Description

A "contact wear strip" is basically a small length of contact wire installed in parallel next to a worn piece of contact wire. (Worn contact wire generally appears at pull-off arms, restricted droppers, turnouts, and any place where the pantograph sees a "hard spot" in the contact wire.)

These wear strips have their ends bent upwards ("bell-mouthed") to help promote smooth pantograph running without causing any abrupt striking action, snagging or arcing. Refer to *Figure 164*.

3.1.13.2 Function

Contact wear strips are installed where the contact wire has worn to unacceptable levels compared with the general surrounding wire thickness. Sometimes they are installed before any wear even takes place (if it is known that this is likely to happen) as a preventative action.

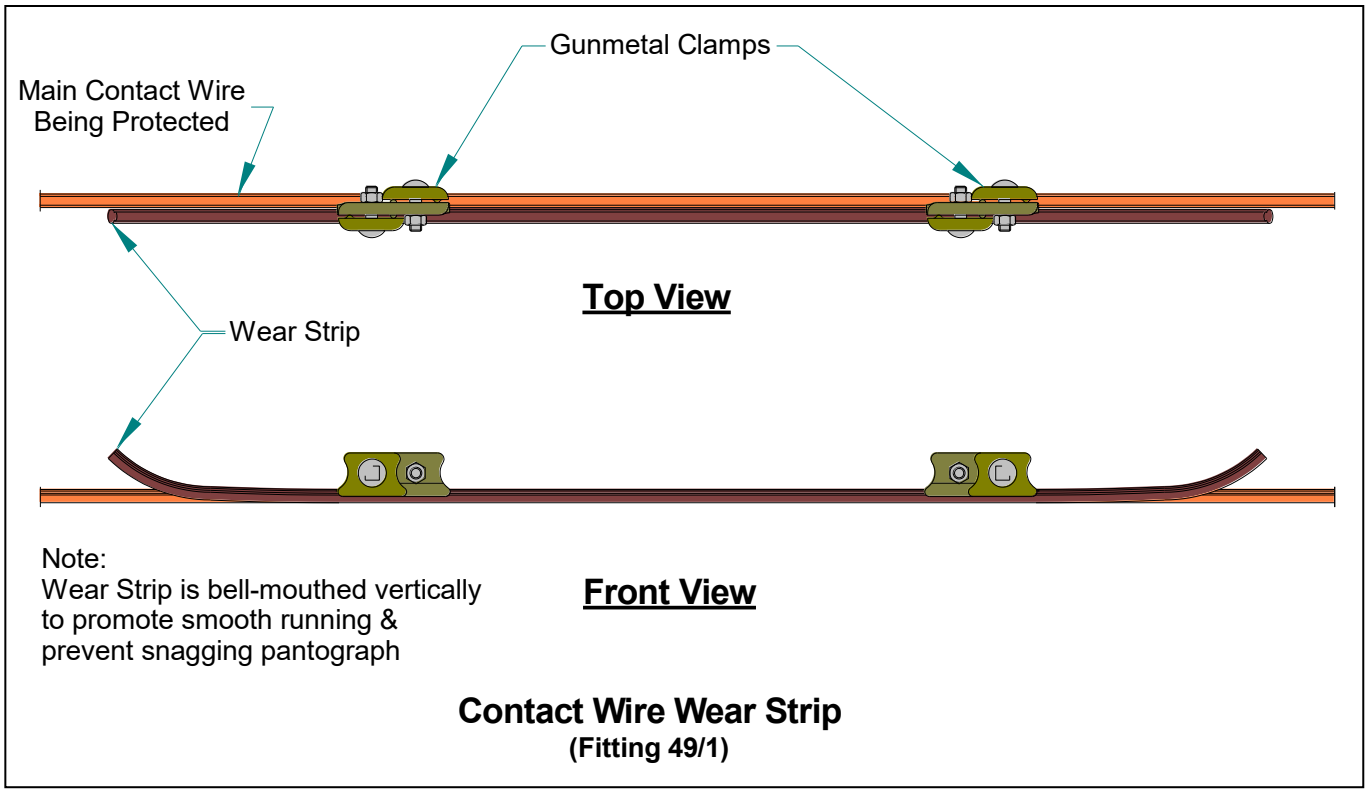


Figure 164 - Contact Wear Strip arrangement

The role of a wear strip is basically to prevent further wear of the already worn contact wire, which risks breakage of this highly-tensioned wire. It is thus considered a "sacrificial" device.

It is not intended that the wear strip reduce the amount of tension in the worn contact wire – indeed the strips are under no tension. They simple clamp to the side of the main contact wire.

3.1.13.3 Typical Components

A wear strip is a relatively simple and inexpensive arrangement that includes a short length of contact wire (of the same size as the main wire being protected from further wear), and 2 (or more) side-by-side contact clamps.

I think these gunmetal clamps are the same as used in the Type 5 section insulator which, in that case, hold each of the side runners next to the main contact wire at both ends of the SI.

3.1.13.4 Configuration

A contact wear strip consists of a short length of contact wire, the same size as the contact wire being protected. The thickness of the running ends of the wear strip should match the underside level of the main contact wire, to prevent any abrupt striking by passing pantographs.

This strip is attached next to the worn contact wire using appropriate contact clamps, with one clamp at each end of the strip. If needed, the strip can be located slightly lower than the worn contact wire, clear of the pantograph running, to prevent any further wear (although the worn wire would normally be thinner and thus higher anyway).

If the contact wire has side wear (e.g. due to pantographs forking-in at turnouts), then the wear strip is installed on the worn side of the contact wire – obviously.

Because the pantographs on superelevated track are not horizontal, this also needs to be taken into account when properly aligning the wear strip at setup. Ideally the common bottom level of both the contact wire and its wear strip should be parallel to the track at both ends of the strip, so that the oncoming pantograph will more likely have a smooth path.

The wear strip is usually up to about 1m long, but it can be as long as 3 or 4 metres in certain circumstances (e.g. for regulated wire at turnouts). Long lengths would require more attachment clamps to help support the device.

The wear strip is installed and aligned so as to allow a smooth pantograph passage. The ends of the wear strip are bent upwards to promote smooth take-up and running.

The wear strips themselves need to be periodically checked for excessive wear and smooth pantograph take-up as they pass through. Also, they should be checked for any signs of the attachment bolts working loose (although this is unlikely if properly installed).

3.1.13.5 Design Notes

There are normally 2 sets of OHW at a turnout – one for the through track and one to service the turnout track.

The greater the angle of these 2 converging sets of wires, the greater will be the likely impact when pantographs pass through. The impact mostly comes from the stainless steel edge of a pantograph horn as it meets the adjacent oncoming contact wire and tries to pick it up and follow it. In the process, the side of the oncoming contact wire can be worn by each passing pantograph as the SS edge of the pan hits and drags along the contact wire for a short distance.

The type of side wear on the affected contact wire is shown back in *Figure 55*. Such turnout situations can be seen further on in *Section 5.1.29*, with accompanying diagrams *Figure 610* and *Figure 611*.

The contact wear is a function of train speed and also of the relative contact heights – the closer they are to being the same level, the better in terms of side contact wear. Note that this situation may need to take into account any track superelevation.

Common practice when designing regulated OHW is to cross the turnout contact wire about 30 to 50mm above the main line contact wire where they cross (in plan view). This allows for the installation of a sliding knuckle on the main line contact wire that then traps the crossover wire (below the top wire of the knuckle arrangement).

In this way both sets of wires can move longitudinally in an unrestricted manner as temperature changes, but just as importantly, they both move vertically together, which is good. Note that the greater the vertical separation of contact wires at the forking-in point, the greater the amount of exposed pantograph horn, and so the greater the wear rate and the longer the actual wear on the affected contact wire.

In fixed-anchored wiring however, it was almost mandatory to have the 2 sets of contact wires come together at the same level (because of the huge tension variations and the likelihood of consequential height variations with temperature).

This configuration was referred to as a "flat knuckle arrangement". It sometimes resulted in some weird and complex situations where the contact wire of the main line run would meet the other contact wire at the junction, then be supported by the catenary wire of the turnout run. This made tracing the catenary & contact wire runs extremely difficult. (They used to record what happened as catenaries & contacts parted ways, on the old OHW layouts using different line styles, but with limited success I think.)

Unfortunately, even when the 2 wires are at the same level, the pantograph itself can lift the contact wire it's pushing up and this can then cause some side wear on the now relatively lower adjacent contact wire when the pantograph strikes it, at a location a few metres before the junction of the wires. For instance, see the relative placement of contact wear strips at the turnout in *Figure 165*.

Figure 165 - Contact Wear Strips installed at a Turnout

Most turnouts have relatively gentle approach angles which is a good thing, but even this can cause wear over time.

The bigger concern is the sharp angles of a diamond crossover, such as those installed at both the Flyovers and the Flyunders located just south of Central Station. A view of the Flyovers is shown in *Figure 118* in *Section 3.1.5*.

Indeed, the angle is so sharp here that it effectively mandates that the regulated contact arrangement be flat, i.e. the contact wires cannot cross one over the other as normally done in regulated OHW, but instead must remain at the same level. Even so, with any pantograph

uplift lifting one contact wire as it approaches the crossing point, the edge of the pantograph can still strike the next contact wire at its normal (but now relatively lower) level.

In all these cases, a wear strip installed onto the wearing contact wire can ward off any further wear. However, the wear strip itself needs to be periodically examined to make sure it hasn't worn excessively, and if so, it must be renewed. The support clamps should also be periodically checked for tightness.

There's a lot to be gained by spending time to get the contact heights just right so as to minimise any pantograph impact and wear into the future.

It is this situation where a *bowed pantograph* could help enormously in reducing or totally eliminating the side wear on contact wires. However, for this improvement to be instigated, I believe something would need to be done with the multitude of Type 6 SIs located throughout the entire electrified network. For more, see *Section 6.3.2.1*, *A Proposed "Bowed" Pantograph Head*.

Standard EP-08000008-SP, "Crossover and Turnout OHW Geometry", should be referenced for more information on achieving proper contact wire geometry at turnouts.

Refer to *Section 5.1.29* for more information on the likely location of wear strips at turnouts.

3.1.13.6 Status (c. 2014)

Wear strips are intended to prolong the life of the main contact wire.

If too many wear strips are installed over a section of contact wire, then steps should be taken to renew the contact wire. (Refer to current Standards.) This is because each wear strip has to be examined frequently, resulting in heavy maintenance effort and costs, and it also results in reduced reliability in the meantime.

3.1.13.7 Reference

- Standard Arrangement – see drawing EL0026992 (Fitting 49/1).

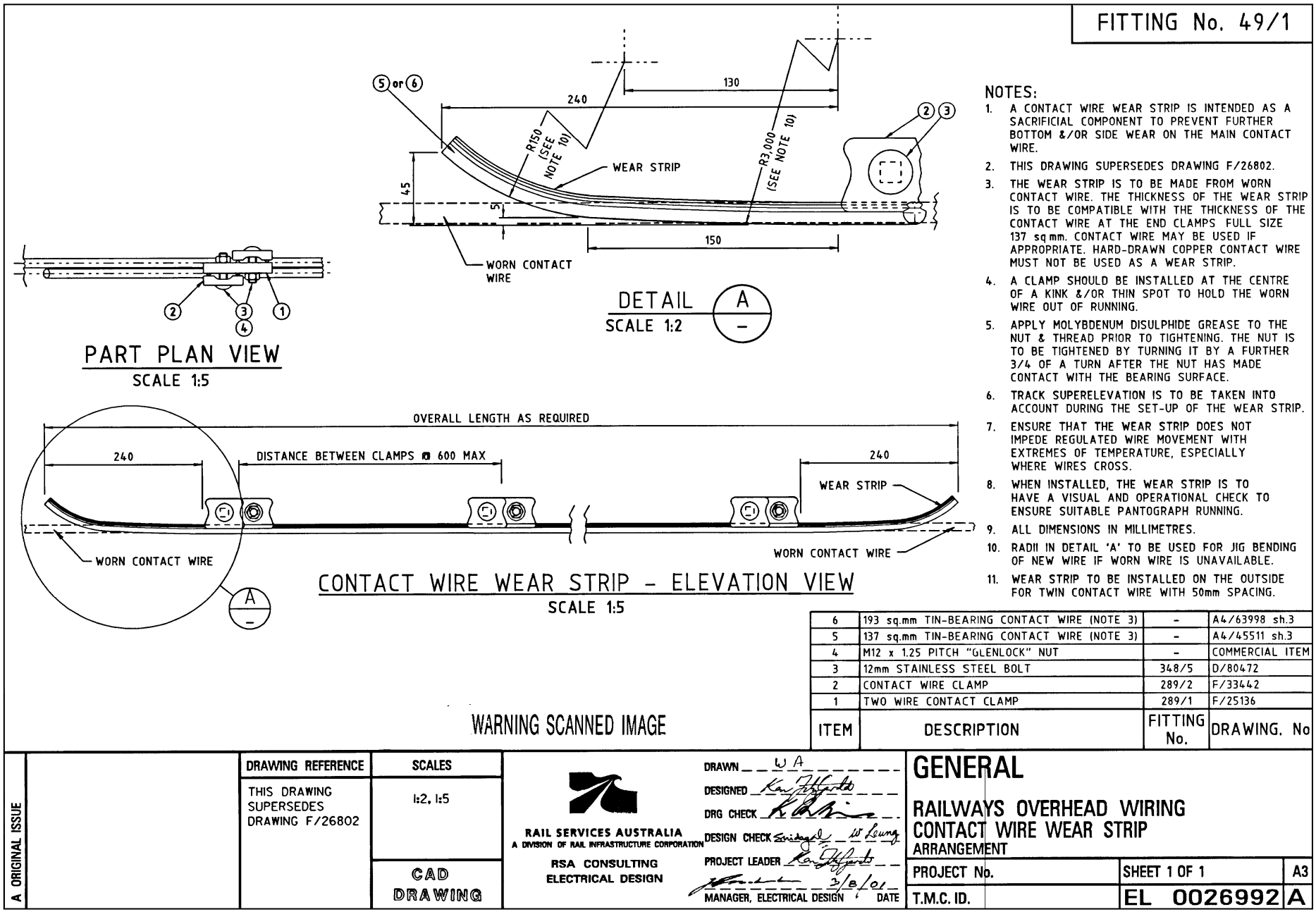
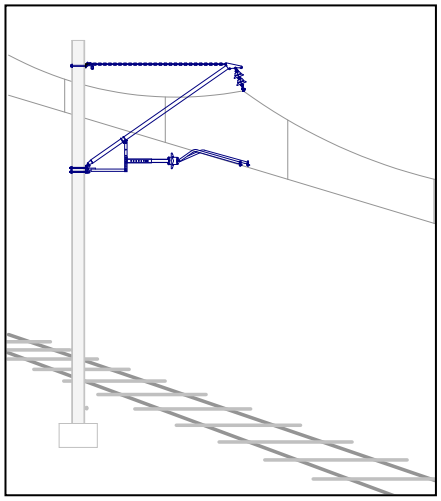

FITTING No. 49/1
5 or 6
240
130
R150 (SEE NOTE 10)
R3,000 (SEE NOTE 10)
WEAR STRIP
45
5
150
WORN CONTACT WIRE
2 3
DETAIL A
SCALE 1:2
2 3 4 1
PART PLAN VIEW
SCALE 1:5
OVERALL LENGTH AS REQUIRED
240
DISTANCE BETWEEN CLAMPS @ 600 MAX
240
WEAR STRIP
WORN CONTACT WIRE
WORN CONTACT WIRE
A
CONTACT WIRE WEAR STRIP - ELEVATION VIEW
SCALE 1:5
NOTES:
1. A CONTACT WIRE WEAR STRIP IS INTENDED AS A SACRIFICIAL COMPONENT TO PREVENT FURTHER BOTTOM &/OR SIDE WEAR ON THE MAIN CONTACT WIRE.
2. THIS DRAWING SUPERSEDES DRAWING F/26802.
3. THE WEAR STRIP IS TO BE MADE FROM WORN CONTACT WIRE. THE THICKNESS OF THE WEAR STRIP IS TO BE COMPATIBLE WITH THE THICKNESS OF THE CONTACT WIRE AT THE END CLAMPS FULL SIZE 137 sq mm. CONTACT WIRE MAY BE USED IF APPROPRIATE. HARD-DRAWN COPPER CONTACT WIRE MUST NOT BE USED AS A WEAR STRIP.
4. A CLAMP SHOULD BE INSTALLED AT THE CENTRE OF A KINK &/OR THIN SPOT TO HOLD THE WORN WIRE OUT OF RUNNING.
5. APPLY MOLYBDENUM DISULPHIDE GREASE TO THE NUT & THREAD PRIOR TO TIGHTENING. THE NUT IS TO BE TIGHTENED BY TURNING IT BY A FURTHER 3/4 OF A TURN AFTER THE NUT HAS MADE CONTACT WITH THE BEARING SURFACE.
6. TRACK SUPERELEVATION IS TO BE TAKEN INTO ACCOUNT DURING THE SET-UP OF THE WEAR STRIP.
7. ENSURE THAT THE WEAR STRIP DOES NOT IMPEDE REGULATED WIRE MOVEMENT WITH EXTREMES OF TEMPERATURE, ESPECIALLY WHERE WIRES CROSS.
8. WHEN INSTALLED, THE WEAR STRIP IS TO HAVE A VISUAL AND OPERATIONAL CHECK TO ENSURE SUITABLE PANTOGRAPH RUNNING.
9. ALL DIMENSIONS IN MILLIMETRES.
10. RADII IN DETAIL 'A' TO BE USED FOR JIG BENDING OF NEW WIRE IF WORN WIRE IS UNAVAILABLE.
11. WEAR STRIP TO BE INSTALLED ON THE OUTSIDE FOR TWIN CONTACT WIRE WITH 50mm SPACING.
6 193 sq.mm TIN-BEARING CONTACT WIRE (NOTE 3) - A4/63998 sh.3
5 137 sq.mm TIN-BEARING CONTACT WIRE (NOTE 3) - A4/45511 sh.3
4 M12 x 1.25 PITCH "GLENLOCK" NUT - COMMERCIAL ITEM
3 12mm STAINLESS STEEL BOLT 348/5 D/80472
2 CONTACT WIRE CLAMP 289/2 F/33442
1 TWO WIRE CONTACT CLAMP 289/1 F/25136
ITEM DESCRIPTION FITTING No. DRAWING. No
WARNING SCANNED IMAGE
A ORIGINAL ISSUE
DRAWING REFERENCE
THIS DRAWING SUPERSEDES DRAWING F/26802
SCALES
1:2, 1:5
CAD DRAWING
RAIL SERVICES AUSTRALIA
A DIVISION OF RAIL INFRASTRUCTURE CORPORATION
RSA CONSULTING ELECTRICAL DESIGN
DRAWN W A
DESIGNED
DRG CHECK
DESIGN CHECK W Leung
PROJECT LEADER
MANAGER, ELECTRICAL DESIGN 3/8/01 DATE
GENERAL
RAILWAYS OVERHEAD WIRING
CONTACT WIRE WEAR STRIP
ARRANGEMENT
PROJECT No.
SHEET 1 OF 1
A3
T.M.C. ID.
EL 0026992 A

Figure 166 - Standard Wear Strip drawing

3.2 SUPPORT & REGISTRATION



3.2.0 General

3.2.0.1 Description

Support & registration (S&R) equipment is the hardware, including 1500V insulators, that hold the catenary and contact wires at a defined position above the track being serviced. The other end of this hardware then transfers the mechanical loadings from the wires over to nearby support structures (such as masts, portals and drop verticals – see *Section 3.3*).

The *Collins dictionary* definition of "registration" is:

(of a mechanical part) to align (with another part).

Support & registration arrangements can be as simple as insulators with associated steel brackets attached to tunnel linings. However, more commonly in the open route, special triangular-shaped frames called "cantilevers" (see above image) are installed on masts or portal structures, to support and accurately register these wires in their correct position.

The location where the catenary wire is supported defines the start of the next *bay* as well as the end of the previous bay.

Most S&R arrangements include a pull-off arm (or 2 arms if twin-contacts are installed). These arms connect to and position the contact wire/s laterally, giving them a defined *stagger* (relative to the superelevated track), while keeping well clear of passing train pantographs.

The category of *support & registration* offers, by far, the widest range of equipment in Sydney's OHW system. This is because of the variety of variables involved, including:

- The *vintage* of the equipment (1930s through to current day),
- The conductor *tensioning mode* (regulated or fixed-anchored),
- *Configuration of catenaries and contacts* (e.g. twin catenary OHW, contact-only OHW, compound OHW, etc.),
- The *surrounding environment* (e.g. open air, tunnel, overline bridge, etc.),

3.2.0.2 Function

Support & registration arrangements provide the means of accurately *positioning* the catenary and contact wires above a track. Both the *height* and *lateral* (stagger) positions are important, and they should be within nominated tolerances of the design position of track at each location.

In addition, S&R arrangements support the resulting *weight* of the OHW conductors and other attached equipment in both adjacent bays, and/or they register any horizontal *radial loads* and *wind loads* imposed by these conductors.

A *pull-off arm* is needed to hold the contact wire in its position, whilst providing mechanical clearance to all passing pantographs. The arm needs to *pivot* at its remote end, to allow the contact wire to rise a small amount as each pantograph passes through, which is designed to prevent mechanical fatigue of certain parts that will need to cope with the numerous pantograph passages every year.

In the case of regulated OHW, they also allow the catenary and contact wires to *move longitudinally* as these wires expand and contract in length when their temperature changes. This in turn allows the conductors to maintain their design tensions and subsequent characteristics (sag, blowout, etc).

Figure 168 shows what constitutes an OHW support & registration arrangement in a typical bay of OHW in the open route. Two cantilevers are shown in blue – the left one is installed on a portal leg beside the Down track and the other is on a drop vertical installed between tracks to service the Up track.

The regular spacing – *bay length* – of OHW support & registration arrangements (along with their support structures), is generally a function of the horizontal track curvature, however the maximum spacing is limited to 67m these days. (It used to be 73m in the old fixed-anchored system, but this had significant limitations as discussed later on.)

Refer to the first 2 columns of the relevant *Structure Spacing Chart*, showing track radius and corresponding maximum bay length (a typical one is shown in *Figure 169*). These spacing charts exist as standard drawings for each OHW system, and they contain all sorts of useful information.

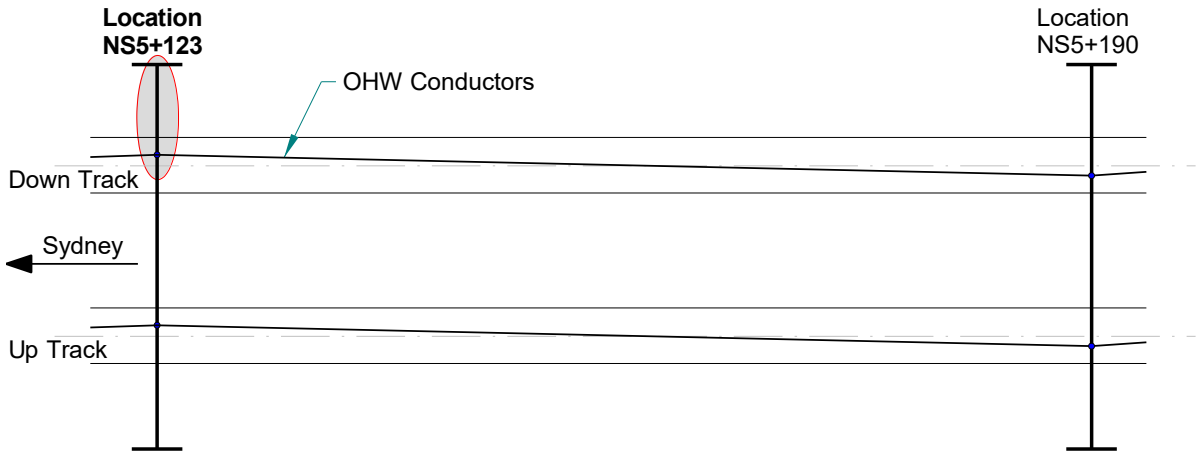
Figure 167 - Interurban Train under Compound OHW System

OHW Support & Registration

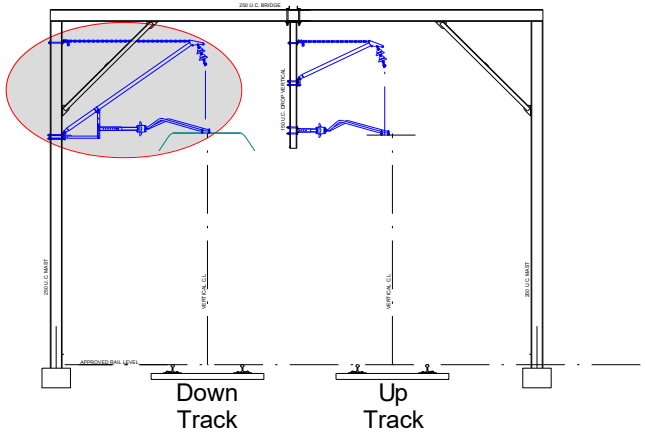
OHW Support & Registration

Asset
NS5+123, Down Track

Includes ... Cantilevers
Portal Suspension Arrangements
Polygons
Pull-Off Arrangements
Bridge Arrangements
Tunnel Arrangements

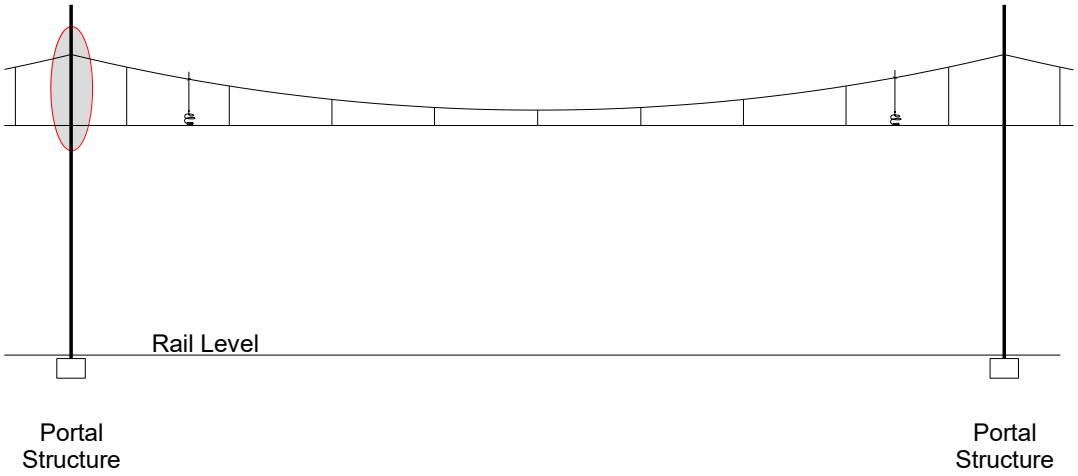


Top View



Location NS5+123

Left End View



Front View

Figure 168 - OHW Support & Registration – boundary

Waterfall to Pt Kembla - Regulated - Catenary=270@30kN : Contact=2x137@12.5kN : System T/w=588m

Spacing Chart ...

Written by Ken FitzGerald

O.H.W. STRUCTURE SPACING CHART

Regulated - Single Catenary / Twin Contact

(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)	(j)	(k)	(l)	(m)
			CONTACT						CATENARY		SYSTEM	
RADIUS OF CURVE (m)	STRUCTURE SPACING (m)	VERSINE AT MID-BAY (mm)	STAGGER (mm)	MID-BAY STAGGER (mm)	BLOW-OUT (mm)	RADIAL LOAD (N)	DYNAMIC WIND LOAD (N)	ADVERSE CONDITION (N)	RADIAL LOAD (N)	DYNAMIC WIND LOAD (N)	STATIC WEIGHT (N)	DYNAMIC WEIGHT (N)
200	28	490	300	-190	60	3,500	647	2,853	4,200	699	1,428	2,496
250	31	481	300	-181	74	3,100	717	2,383	3,720	774	1,581	2,649
300	34	482	300	-182	89	2,833	786	2,047	3,400	849	1,734	2,802
350	36	463	300	-163	100	2,571	832	1,739	3,086	899	1,836	2,904
400	38	451	300	-151	111	2,375	879	1,496	2,850	949	1,938	3,006
450	40	444	300	-144	123	2,222	925	1,297	2,667	999	2,040	3,108
500	42	441	300	-141	135	2,100	971	1,129	2,520	1,049	2,142	3,213
550	43	420	300	-120	142	1,955	994	960	2,345	1,074	2,193	3,290
600	45	422	300	-122	156	1,875	1,040	835	2,250	1,124	2,295	3,443
700	48	411	300	-111	177	1,714	1,110	605	2,057	1,199	2,448	3,672
800	50	391	250	-141	192	1,563	1,156	407	1,875	1,249	2,550	3,825
900	52	376	250	-126	208	1,444	1,202	242	1,733	1,299	2,652	3,978
1,000	54	365	250	-115	224	1,350	1,248	102	1,620	1,349	2,754	4,131
1,100	56	356	250	-106	241	1,273	1,295	-22	1,527	1,398	2,856	4,284
1,200	57	338	250	-88	250	1,188	1,318	-130	1,425	1,423	2,907	4,361
1,300	59	335	250	-85	267	1,135	1,364	-229	1,362	1,473	3,009	4,514
1,400	60	321	250	-71	276	1,071	1,387	-316	1,286	1,498	3,060	4,590
1,500	61	310	250	-60	286	1,017	1,410	-394	1,220	1,523	3,111	4,667
1,600	62	300	250	-50	295	969	1,433	-465	1,163	1,548	3,162	4,743
1,700	63	292	250	-42	305	926	1,457	-530	1,112	1,573	3,213	4,820
1,800	64	284	250	-34	315	889	1,480	-591	1,067	1,598	3,264	4,896
1,900	65	278	250	-28	324	855	1,503	-648	1,026	1,623	3,315	4,973
2,000	66	272	250	-22	335	825	1,526	-701	990	1,648	3,366	5,049
4,000	67	140	150	10	345	419	1,549	-1,130	503	1,673	3,417	5,126
6,000	67	94	100	6	345	279	1,549	-1,270	335	1,673	3,417	5,126
8,000	67	70	100	30	345	209	1,549	-1,340	251	1,673	3,417	5,126
TANGENT	67	0	+/-250	0	345	+/-373	1,549	-1,176	+/-448	1,673	3,417	5,126

This column affects the number of structures required per kilometre (generally).

These columns affect the load on the OHW structure. (See above stick diagram)

Note:
Official Structure Spacing Chart for OHW System 2 is on drawing D/84941 sh. 2 (EL0009386)

OHW DETAILS

SYSTEM :

T/W (m) :	588.2
Weight (N/m) :	51.0
Wind Velocity (kph) :	130

CATENARY :

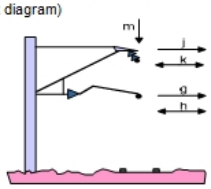
Area (sq.mm) :	270
Stranding (mm) :	37/3.05
Material :	HD Cu
Diameter (mm) :	21.34
Tension (kN) :	30
Weight (N/m) :	23.97

CONTACT :

Area (sq.mm) :	2x137
Material :	HD Cu
Diameter (mm) :	13.72
Tension (kN) :	12.5
Weight (N/m) :	11.87
Contact Blowout ...	
Tension (kN) :	12.50
Wind Speed (km/h) :	130

Notes :

1. Catenary Radial Loads in table are at Design Tension and are already multiplied by 2 if twin catenary.
2. Catenary Wind Loads in table are at System Wind Speed and are already multiplied by 1.8 if twin catenary.
3. Contact Radial Loads in table are at Design Tension and Are already multiplied by 2 if twin contact.
4. Contact Wind Loads in table are at System Wind Speed and are already multiplied by 1.8 if twin contact.
5. Catenary Dynamic Wind Load factor allows for gusting winds. (Dynamic = Static x factor)
6. Catenary Stranding factor allows for additional wind drag on conductor strands. (Load = Dynamic x factor)
7. Contact Dynamic Wind Load factor allows for gusting winds. (Dynamic = Static x factor)
8. Total Contact Wind Load factor allows for shielding from wind for 2nd contact wire. (Total = Wind Load x factor).
9. Dynamic Weight Load = Static Weight Load x 1.5 **or** Static Weight Load + 1,068N (whichever is the greater).
10. Contact Blowout factor = 1.0 for single contact and 0.9 for twin contact (1st contact wire partially shields the 2nd from wind).



Variables :

Catenary Wind Load factor	3.693E-05
Catenary Dynamic Wind Load factor	1.5
Catenary Stranding factor	1.25
Total Catenary Wind Load factor	1
Contact Wind Load factor	3.693E-05
Contact Dynamic Wind Load factor	1.5
Total Contact Wind Load factor	1.8
Mast Spacing Allowance (m)	1.5
Blowout constant	0.0046
Maximum Bay Length (m)	67
Blowout factor	0.9

Figure 169 - Typical OHW Structure Spacing Chart – 270mm² Catenary / 2x137mm² Contacts (System 2)

3.2.0.3 Typical Components

There's a multitude of components that are used in various support & registration equipment, and some components are also used in other types of OHW equipment (e.g. the 16mm diameter stainless steel pins, which are also used in section insulators).

At this point it might be useful to show some details of the fundamental components that are commonly used in past and current support & registration arrangements:

- Insulators
- Catenary Suspension Attachment
- Insulator Link Bar
- Pull-off Arm
- Contact Swivel Clamp
- Copper Span Wire
- U-Bolt Clamp
- Twisted Sleeve
- Thimble
- Turnbuckle
- Spreader Bar
- Insulated Stop Beam

More components are described in the relevant S&R categories that follow, e.g. in *Section 3.2.1, Cantilever Arrangements*, etc.

INSULATORS

Insulators provide a means of mechanically connecting various parts of equipment together so that one side (the OHW conductors) can be reliably operated at 1500V, even under heavy rainfall and other adverse conditions.

Various types of insulators provide the necessary 1500V electrical insulation:

- Between the catenary wire and its support frame, and/or
- Between the contact wire (held by its pull-off arm) and its registration equipment.

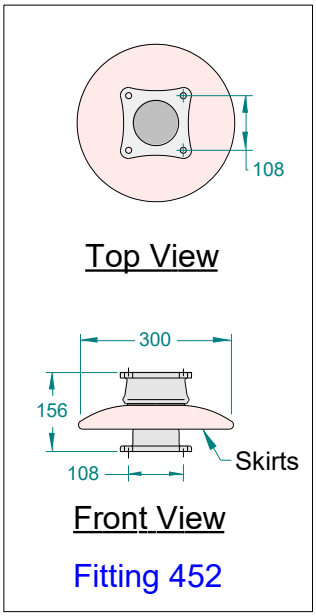
Insulators for support & registration in the 1500V OHW system are normally made using one of 3 insulation technologies:
porcelain, *fibreglass* or *cycloaliphatic resin* (these were described in *Section 2.9*).

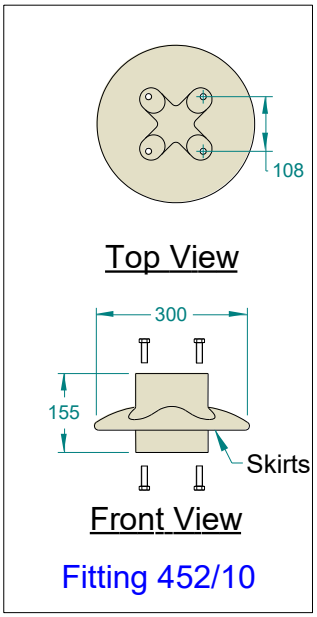
Post Type Insulators

These are fittings 452 and 452/10.

A 305mm (12") diameter insulator, with 4 holes on the "cap" aligning with 4 holes on the "base", which are provided for rigid attachment to the catenary suspension or pull-off ("post") arrangements.

Fitting 452 is the original porcelain insulator with dark brown or light grey porcelain. It has galvanised steel flanges on both sides of the insulator, and each flange has 4 holes to connect to other hardware using M12 bolts, nuts and spring washers. The 4 holes are spaced 108mm apart (on a 152mm pitch circle diameter).





Fitting 452/10 is a newer "cycloaliphatic resin" insulator. This was introduced in the late 1990s as a substitute for the 452 insulator (some of which had significant corrosion problems over time).

This recent insulator is lighter and stronger, and if the skirts are accidentally chipped, they are not as sharp as the razor-sharp edges of the chipped porcelain insulator. Significantly, nothing in this insulator can corrode over time. However, instead of holes, it has M12 oversize threaded brass inserts – 4 on each side of the insulator and with the same hole spacing as the 452 insulator above. These threaded inserts accept galvanised set screws when fastening to the next component (their oversize internal threads are to allow for thick hot-dip galvanised coating on the set screw threads). Having the threaded brass inserts can sometimes limit the ways this connects to other parts, so various adaptor plates have been developed to help overcome this issue. This insulator is grey or brown in colour.

Figure 170 compares the *creepage distance* of the 2 post type insulators, with the resin insulator apparently having about 25% longer creepage distance in its minimum path (between the steel connecting flanges at both ends of the insulator). This is a good outcome for minimising dc leakage currents across the insulation surface.

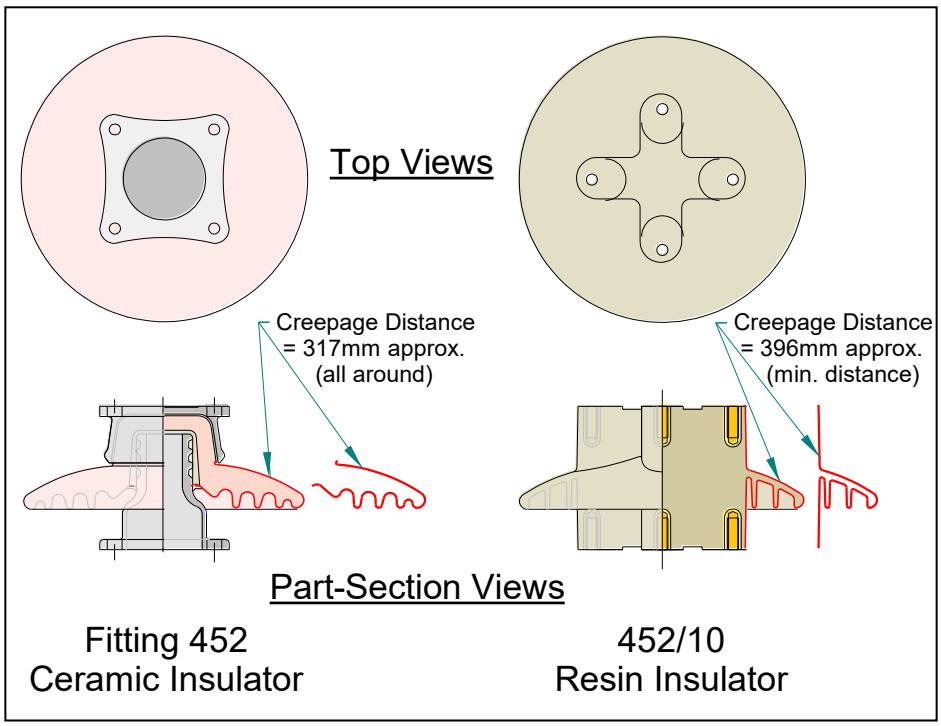


Figure 170 - Comparison of creepage distance for 452 ceramic and 452/10 resin insulators

The post type insulator is most commonly installed on the end of a horizontal metal post (thus the name?), with the live end of the insulator holding the pull-off arm with the aid of an appropriate pull-off clevis fitting and pin (allowing the arm to pivot). Pairs of these insulators are also used in bridge OHW support arrangements, where the insulator is oriented upwards and placed in compression, supporting a galvanised steel "L-iron" or "T-iron" fitting (one insulator is installed at each end of this fitting). This insulator is also used in low tunnels (placed in tension) to support the OHW.

There are also instances where the catenary is suspended from a portal bridge through 1 or 2 post type insulators (e.g. one version of the fixed mid-point anchor arrangement has this).

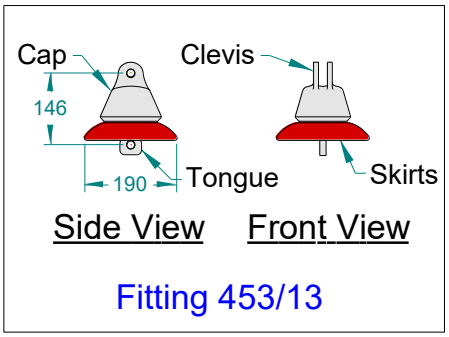
Figure 171 - Cracked resin in early 452/10 insulator

Some early versions of the 452/10 resin insulator had the top-most part of each of the 8 threaded brass inserts located a few millimetres *below* the resin surface (see *Figure 171*). If an M12 set screw was heavily tightened against its connecting steel flange, this sometimes led to the resin cracking in this area (see picture). In essence, this placed enormous stress on the small gap of resin, as well as trying to pull the knurled brass insert out of its resin socket. The remedy was to bring the brass insert all the way to the insulator surface, as this allowed the set screw to fasten the flange against brass (not resin). If any instances of cracking are seen in the field, the insulator should ideally be replaced.

Refer to Standards:
EP-08000019-SP, "Performance Specification for OHW Post Type Insulator Units", and
EP-08000021-SP, "Insulator Type Tests – DC Power Arc Withstand".

Suspension Insulators

For most OHW work, these are disc insulators, fitting 453/13. They are 190mm diameter insulators intended for supporting and registering the OHW conductors. They are not strong enough to take in-line tension.



They have a clevis on the top cap and a tongue at the bottom end. This allows a 16mm diameter pin connection to relevant hardware at both ends, as well as for coupling 2 (or sometimes more) insulators together in series, to improve the flashover voltage rating.

Insulator Orientation

Although it cannot always be done, porcelain insulators should ideally be installed with the steel cap on the +1500V side and the tongue on the support structure side, so as to reduce the effect of electrolytic dc corrosion of any steel parts associated with the insulator.

In this way, electrolytic corrosion occurs on the cap, which has a much larger surface area and can cope better with the corrosion over time. This results in a lower leakage (corrosion) current density, than when it passes onto the insulator tongue (which has a comparatively small surface area and volume).

Figure 172 - Corrosion on insulator tongue due to electrolysis

However, contrary to the above ideal, catenary support insulators usually require that the insulator cap be attached to the support structure, so as to orientate the insulator skirts properly. (The skirts are designed to shed water, increase the current leakage path and improve flashover performance in wet conditions.) Sadly, this configuration causes the smaller diameter tongue to corrode instead of the cap – see *Figure 172* for instance.

Sadly, this situation cannot be avoided, and so the OHW support arrangements have to be regularly examined for signs of excessive corrosion on the insulator tongue/s. These insulators have stainless steel or zinc sleeved steel tongues, to slow down the effects of electrolysis. The post type insulators used in conjunction with "L-irons" as support arrangements at bridges, are better off since they are configured to place the cap on the +1500V side (which of course was deliberate).

Refer to EP-08000020-SP, "Performance Specification for OHW String Insulator Set".

Loop Strain Insulators

Loop strain insulators are commonly installed in older arrangements, at the lower end of a long solid copper dropper that connects to the catenary and supports a cross-span to which the pull-off arms attach. I think they're called "Buller" insulators (named after a manufacturer).

The purpose of this insulation is to prevent any small levels of dc current, of the same electrical section, finding alternate paths through more vulnerable fittings such as mild steel and stainless steel pins, etc. Refer to *Figure 185* further on which shows a single loop strain

insulator lifting a cross-span wire to gain suitable clearances. See also *Figure 577* much further on for a closer view of one such unit.

In this situation, the voltage across the insulator would probably be less than 1 volt, but it's the relatively small dc current that would otherwise pass through the connection that does the damage over time, and therefore needs to be stopped using this insulator.

Sometimes a series pair of loop strain insulators have been used in pull-off span arrangements as the primary insulation positioned back at the mast. This cheap insulation would typically only occur in yards where the loss of supply due to flashover might have been more tolerable in the old days. (Flashover is more likely due to the absence of insulator skirts or sheds, and shorter flashover distances.) This configuration still exists in many yards today.

Newer S&R arrangements no longer rely on this cross-span arrangement (due to the requirement for *independent registration*), so there's no need for the loop strain insulator.

CATENARY SUSPENSION ATTACHMENT

These are fittings that connect the catenary from the supporting insulator above it, in a way that does no damage to the catenary wire.

Suspension Envelope

In the far majority of situations, the catenary is attached by means of a "catenary suspension envelope" fitting (e.g. fitting 98/4 for 270mm² and 327mm² catenary wires). See *Figure 173* as well as *Figure 174* (located at the end of the Mk-2 Tunnel Cantilever).

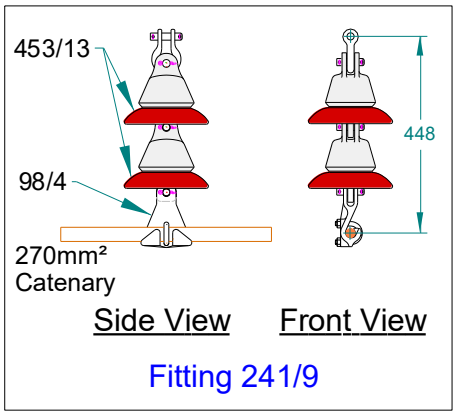


Figure 173 - Catenary Suspension arrangement

The catenary is lowered into this gunmetal fitting, and clamped in place with a single U-bolt clamp and a protective gunmetal packing piece to help spread the clamping load and not damage the catenary strands.

The envelope fitting itself can swing longitudinally as the catenary moves about.

The really good thing about this arrangement is that it's most unlikely to fatigue in time, and this includes the vital connection to the catenary wire itself. This is due to the sheer number of pin connections, which provides the necessary freedom for any parts to move if needed (without inducing undue stress).

Figure 174 - Catenary Suspension Envelope

If there is a down side to this arrangement, it's that the catenary will "swing" laterally to an equilibrium position with the resultant radial load / weight load combination. This causes changes to height and stagger, which need to then be taken into account to deliver the correct height and stagger for the location. This is discussed further in *Section 3.2.0.5*, *Insulator Swing*.

Suspension Clamp

A less common arrangement uses a cast gunmetal plate ("butterfly clamp").

This fitting sandwiches the catenary to a post type insulator, and places the insulator supporting the catenary in tension (or sometimes in compression), e.g. fitting 296/1. See *Figure 175* (connected to a 452/10 insulator).

Its curved bell-mouthing helps provide a soft interface to the catenary strands as this wire sags in adjacent bays.

This is most commonly used with fixed-anchored OHW located inside tunnels.

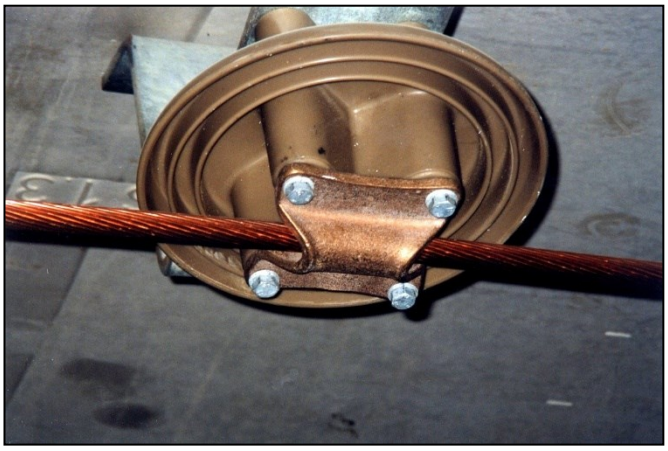


Figure 175 - Catenary "Butterfly Clamp"

TRIPLE INSULATION

Throughout the electrified network there are situations that use 3 suspension insulators instead of the normal twin insulators. They have basically been installed for one of two reasons:

- To allow for convenient conversion to 25kV should that ever eventuate (e.g. Cowan area, decided in the 1990s). It was thought that the 3rd insulator should combine to provide the necessary insulation level for this higher voltage. The CCalc computer program was modified to easily incorporate the 3rd insulator if required at specific locations. Refer to *Figure 176*.

Figure 176 - Cantilevers with 3 suspension insulators for option of later 25kV conversion (~ Cowan)

- To provide a convenient tap-off point for bonding in a *secondary insulation* scheme. The lower end of the top-most insulator can have a bolted lug connection that connects to the bonding circuit to provide an enhanced bonding scheme.
  This scheme then has the mast or portal earthed, with the independent bonding wire going to rail (via spark gap?). The other 2 insulators are for normal primary insulation of live catenary wire.
  This configuration provides a good solution for OHW structures installed on crucial structures, such as on viaducts and underline bridges, where electrolysis leakage currents cannot be tolerated. This has become almost standard practice in recent years as it is easy to achieve and has been considered to be a good way of controlling the electrolysis hazard.

For the 2nd dot point, refer to *Figure 177*. Again, the CCALC computer program can conveniently provide allocation for the 3rd insulator in this situation.

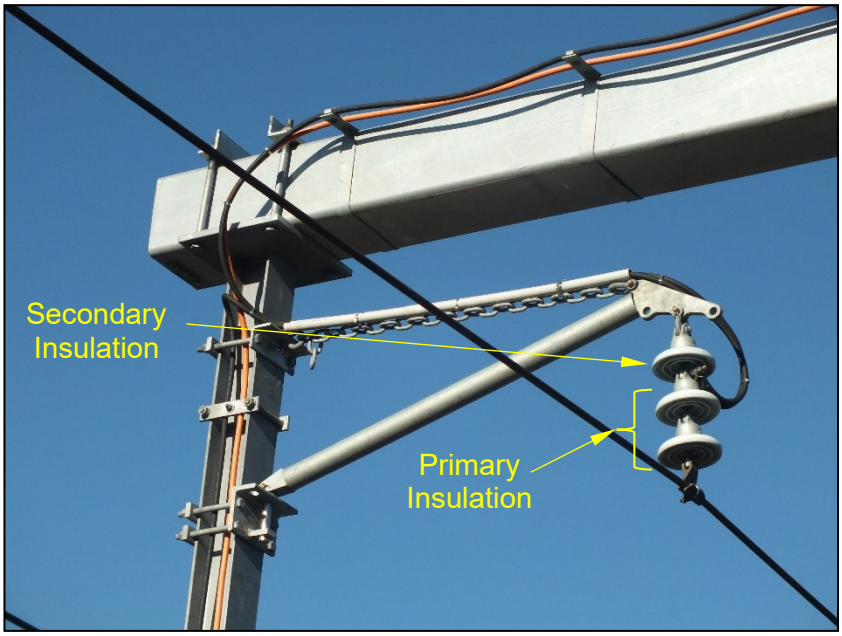


Figure 177 - Third insulator used for Secondary Insulation

INSULATOR LINK BAR

Sometimes when there's a pair of side strain insulators (Fitting 453/13) in pull-off arrangements, they include a 75mm or more likely a 150mm long (between pin centres) "link bar" installed between them. Refer to *Figure 178(b)*.

The link bar has been made from galvanised steel in the past, but currently fittings 312/14 and 312/15, made from cast stainless steel, are the preferred option. These cast items are affectionately known as "doggy bone spreaders" (for obvious reasons).

What follows is just my understanding of how the insertion of this spreader bar might improve the reliability of the OHW system when it comes to lightning flashovers.

The purpose of this bar is to increase the distance between insulator skirts, which then increases the flashover distance. With this, during periods of heavy rain, lightning is less likely to flashover here. (This is apparently achieved without significantly affecting the insulation coordination of the OHW system.)

If flashover does occur, the rising arc is more quickly extinguished because of the extended length, which is important.

Each insulator has skirts that are designed to keep that part of the insulator dry, even during heavy downpours, but this can only be achieved if the insulator is vertical or near so.

However, the pull-off insulators are mostly horizontal, and sometimes when setting the pull-off arm heel height they even aim downwards, exposing the skirts to rain. So, in heavy rain there may be one or several continuous narrow (but conductive) water streams across both insulators, between live OHW and the earthed mast structure. The resistive stream path can promote flashover with induced voltages on the line. My guess is that this has caused problems in the past with flashover from edge of insulator to remote edge of the second insulator, and the addition of the link was the preferred solution to help the situation in this regard (as shown in *Figure 178*).

Lightning seems to prefer to travel the shortest distance and in straight lines (and its convection heat tends to make the arc rise to the higher level where possible). So, lightning may or may not choose to run along the conductive link bar, but instead travel through the shorter distance in air (which it can do due to its rapid current rate-of-rise and relatively low impedance in air). With the link bar installed, the flashover distance is thus 150mm longer

and therefore it's less likely to flashover than without the spreader. And as mentioned, it will extinguish an arc more rapidly too.

This policy is not implemented in all instances – only for new or upgraded equipment installed since about the 1970s – 80s. For example, see *Figure 184*, which is an older situation with no spreader, and *Figure 185* which is from Gosford to Newcastle (1980s) showing a 150mm spreader between side-strain insulators on the left mast.

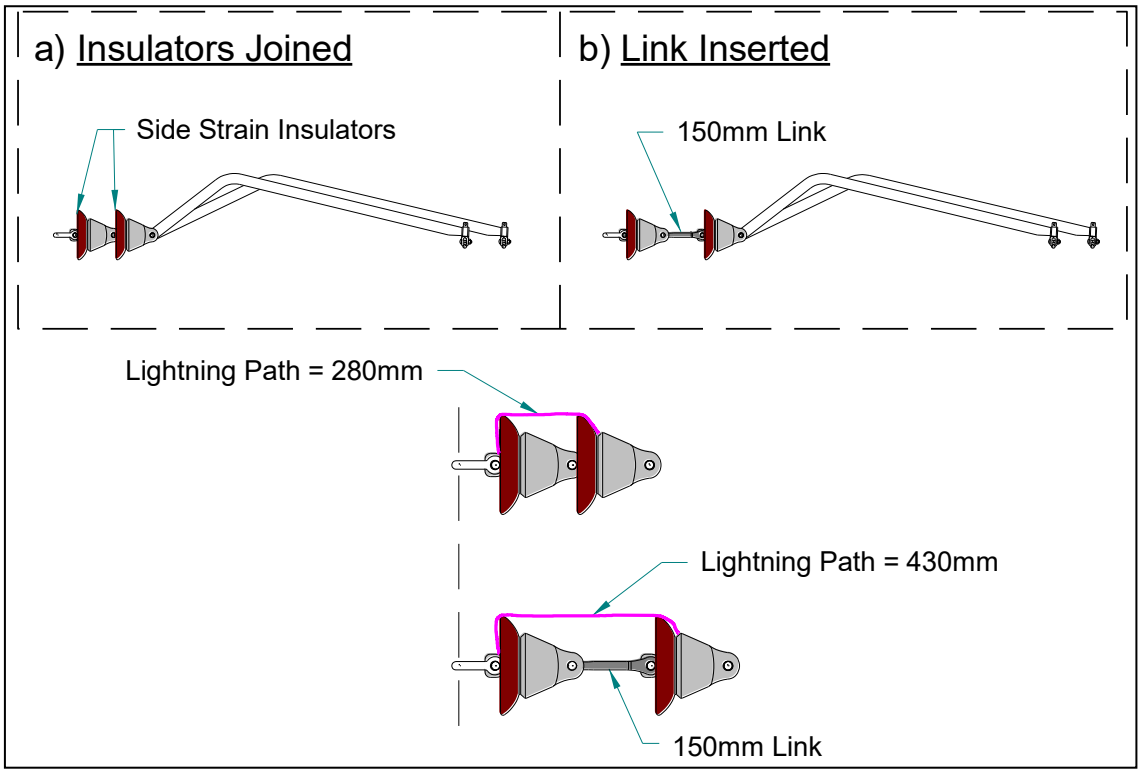


Figure 178 - Insertion of Link improves lightning flashover distance

PULL-OFF ARM

A "pull-off arm" is a fitting designed to register the contact wire whilst providing adequate mechanical clearance to passing train pantographs. This type of fitting is fundamental to the OHW system, and there are several variants and many lengths of each.

The arm locates and "registers" (holds) the contact wire to give the correct contact stagger relative to the superelevated track centreline at contact height.

It's called an "arm" because most of them take on the shape of someone's outstretched arm, and the end of the arm holds onto the movable contact wire (much as a hand can restrain an object). See *Figure 179*.

The arm must be mechanically strong enough to withstand radial and wind loads exerted on the contact wire being restrained, and not flex too much either.

Typical fitting numbers are in the 954/- or 955/- series these days. For example, 954/52 (top diagram) is a 1.2m long arm suitable for use in single contact systems.

Ideally the pull-off arm should be under tension (excluding wind load), as this promotes a better dynamic interface with pantographs at speed. However, there are some situations where an arm is placed in slight compression for convenience (e.g. on straight or near-straight track) – it's then referred to as a "push-off arm", although it's still generically a pull-off arm (they look the same).

A pull-off arm has 2 ends:

- One end connects to the contact wire – the "contact attachment end".
- The other end connects either directly or indirectly to the insulator – the "heel end".

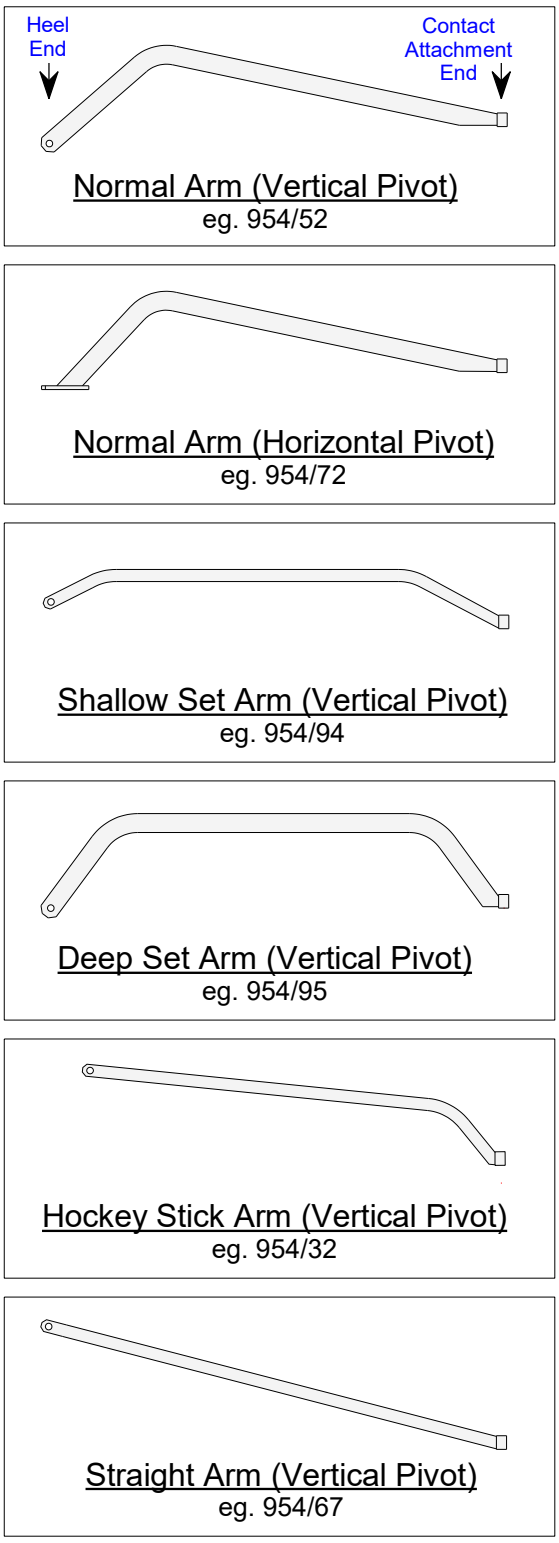


Figure 179 - Common types of Pull-off Arms

Both ends of each arm have provision for some form of pin or swivel connection. This is done to prevent fatigue over time (as a consequence of the likely millions of pantographs passing, with each one trying to lift the contact wire and stress the wire, the arm and its connecting pull-off clamp).

The *contact end* of the arm has a vertical tube (typically 27mm diameter with 20mm bore) welded to the arm, and this accepts the *contact swivel clamp* fitting (61/2) which then grips the contact wire. (Much older clamps used a different "ball and socket" swivel mechanism, but they are far less common these days and diminishing in numbers each year as equipment is modernised.)

The *heel end* has a hole which provides for some degree of vertical (rotational) movement of the arm at this point, to cater for contact wire uplift as a pantograph passes through. Again, the pivoting action prevents cyclic stressing of certain parts and so prevents fatigue over time. Refer to *Section 5.1.8* for more details on preventing fatigue.

In a regulated OHW System, some arms have the heel end as a pivot connection that can also allow the arm to rotate horizontally as the contact wire moves longitudinally with temperature changes – this requires a vertical hole.

Figure 180 shows some actual arm types.

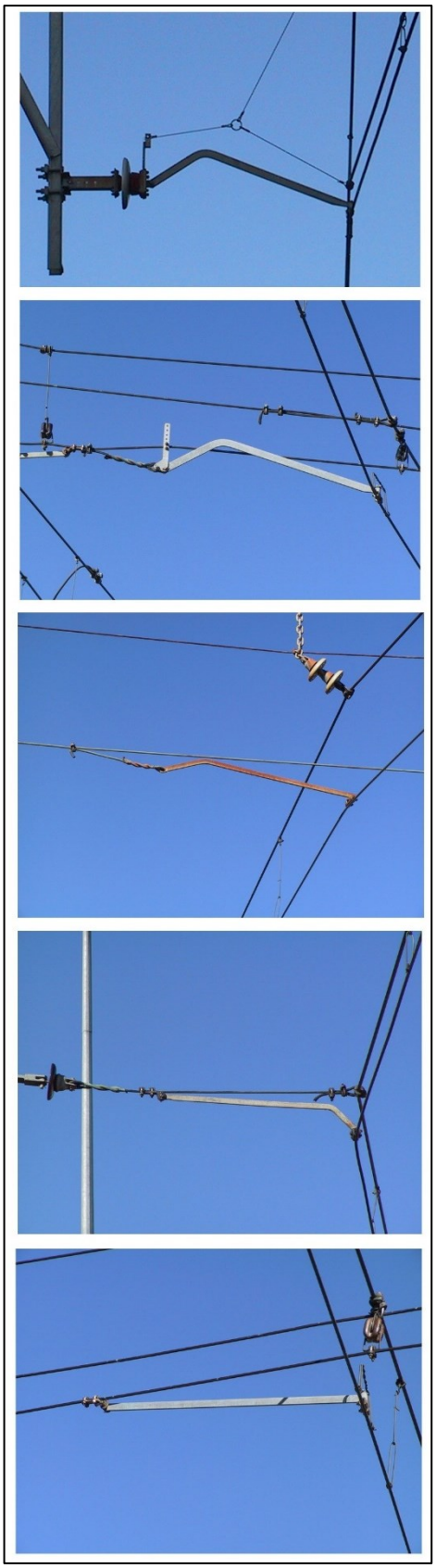


Figure 180 - Some Arm shapes

Pull-off arms come in a variety of shapes and sizes, and they are made of at least 3 different materials:

- *Mild Steel*. This is by far the most common metal used for manufacturing pull-off arms. They are made using a rectangular section of steel, typically 32mm × 8mm, but this section depends on the shape and strength requirements of the arm (especially how much radial plus wind load is to be handled). Hot-dip galvanising coating is essential. Twin contact arms typically use a thinner gauge steel section because their loads aren't as great as the equivalent single contact version (i.e. twin contact tension is less). Also, the aim is to keep the weight of the arm down to the bare minimum to limit the "hard spot" seen by passing pantographs.
- *Stainless Steel*. This metal has been used on the Liverpool to Glenlee Project. A tubular section was selected which makes it relatively light and strong, with no chance of corrosion to failure (although fatigue can be a culprit if you're not careful). There have been problems however with small current feeding through the arm, which can cause accelerated wear at the pivot points.
- *Fibreglass*. This special insulating material has been used in certain tunnels where the clearances in the confined space made it difficult to install the standard post type insulator on the lining of the wall (for using steel arms). Instead, the tubular fibreglass arm itself provided the necessary 1500V insulation (with no post type insulator).

Types of pull-off arms:

- ***Standard Arms***. These arms are actually shaped like a person's arm bent at the elbow. They are the current shape, used on most arrangements now. The elbow offset is intended to gain a certain amount of clearance to passing pantographs when the contact wire is uplifted. The elbow was particularly needed in the past with fixed-anchored OHW, as the uplift with multiple-header locomotives was as much as 300mm or so. The elbow was particularly needed at mid-bay

pull-off locations, especially where a solid horizontal post from the mast held a post type insulator at a fixed height. This meant the full amount of contact rise (with cold temperature and pantograph uplift) had to clear the pull-off arm and not snag it as pantographs passed through. Refer to *Figure 196* further on for what this looks like. However, regulated OHW these days does not need to deal with either of these issues, and so the elbow offset need not be as severe. See *Figure 181*, 2nd cantilever.

- ***Straight Arms***. These arms are straight (as the name says). They were used in the old fixed-anchored OHW system and only on straight track where there was no consequent radial load. Refer to *Figure 236* much further on for an example. The heel of the arm was connected to a clamp installed on a cross-span that was located some 300mm or more above the contact wire level. Any radial load, coupled with the large heel height, would tend to lift the contact wire more as pantographs passed through. Often a "fender" was installed onto the contact wire under the cross-span, to limit the amount of contact uplift and prevent a clash with the pantographs.
- ***Hockey Stick Arms***. Again, these were mostly used for fixed-anchored OHW in certain circumstances of relatively low radial loads.
- ***Deep Set Arms***. These arms are in use today, as they are needed in situations where another contact wire of a different electrical section is located under the arm, and therefore a certain amount of vertical electrical clearance is required between these items (ideally 150mm clearance is needed). They are typically used at feeding overlaps and open overlaps. See *Figure 181* (closest cantilever).
- ***Type "G" Arms***. A pull-off arm is intended to register the all-important in-running contact wire. However, another type of "arm" is used to register the out-of-running contact wire in an overlap, when under low to medium radial loads – in the Types 1G and 2G cantilevers. See *Figure 181* – the 4th cantilever has a horizontal Type 1G arm for the higher out-of-running contact wire. It could be argued that this isn't really an arm because it's not registering an in-running contact wire, and indeed the Type 3G has no such arm – it's just a horizontal length of chain to a fitting that holds the contact swivel clamp. But they both still function to position the contact wire laterally.

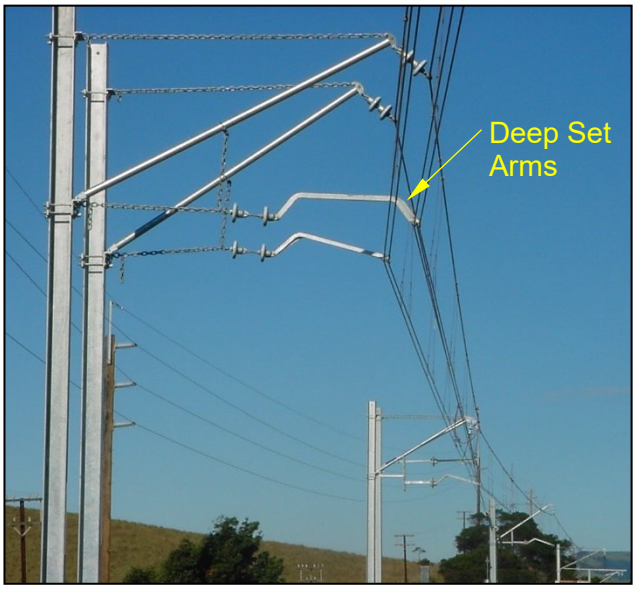


Figure 181 - Cantilever Pull-Off Arms in a 4-bay Feeding Overlap

Suggested Improvement

One significant improvement that should be made to the arms is to get the manufacturer to permanently stamp the arm with its *fitting number and its length* –in large numbers/letters and in a way that can be seen and checked from the ground when installed in the air.

Having this information can help enormously when commissioning any new or altered OHW. And it remains for subsequent reference by maintenance staff or even construction staff if and when the OHW needs to be altered later.

This information is important as it needs to be checked against its design in terms of being the right length and type of arm (both aspects are important), because it's positioned very close to the passing pantographs (the heel end of the arm must clear the pantograph).

The best that could be offered recently is to print this information in permanent marker, which can lead to questions about the accuracy of this information, and it can have mixed (non-standard) results. And it may not be "permanent" (e.g. faded) in 10 years' time.

This would be a simple but very effective improvement, and at minimal comparative cost.

CONTACT SWIVEL CLAMP

These clamps attach to the top notches in the contact wire and so provide the means of attaching the vertical tube (welded at the end of the pull-off arm) to the contact wire. This mechanism allows the pull-off arm to swivel relative to the contact wire, essentially to prevent fatigue.

The most common clamp is fitting 61/2 contact swivel clamp, which is a 3-piece clamp consisting of the main body and 2 identical side pieces – all made from investment cast stainless steel. See *Figure 182*. Two M10 cup-head SS bolts and nuts (fitting 348/22) secure the side pieces to the clamp body, and a washer and split pin are needed at the top.

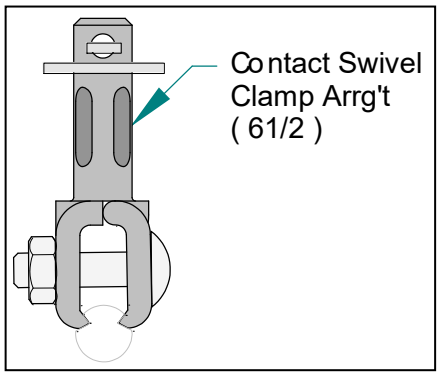


Figure 182 - The standard Pull-off Swivel Clamp

Figure 183 shows how the contact swivel clamp attaches to the pull-off arm.

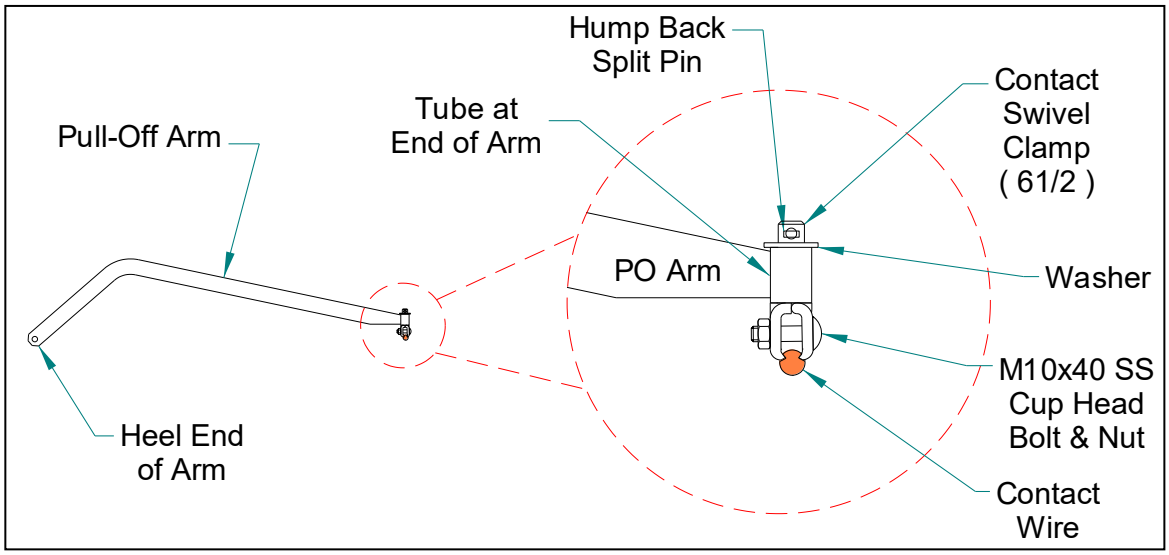


Figure 183 - Pull-off Swivel Clamp connection to Arm

The clamp is secured to either the 137mm² or 193mm² contact wire, using two M10 × 40mm stainless steel cup-head bolts and nuts (with fine pitch metric thread). The bolts have a square neck that fits into the square recess in either casting, and for convenience, this prevents the bolt rotating when tightening the nut.

In the area of a "forking-in point" at turnouts, it is important that the cup head be located on the side closest to the adjacent oncoming track, to prevent it snagging just in case the pantograph horn rides along the lower-side of the contact wire. For more information on OHW at turnouts see *Section 5.1.29*.

There had been some casting problems with the 61/2 fittings in the early 1980s. Apparently, the metallurgical nature of the cast stainless steel was badly affected during manufacture, and this led to some castings developing internal stress corrosion and cracks, that ultimately resulted in clamps failing after a short service period. Fortunately, this was investigated and the proper process for heat treating the casting was then documented on the design drawing for the fitting, resulting in no future problems of this type.

SPAN WIRE

Copper span wire has been used in many of the old arrangements dating back to the 1920s, and is still in use today in some new arrangements. It is generally used to connect a pull-off arm to an insulator, and usually allows for convenient adjustment of stagger.

These days the span wire is 90mm² (37/1.75mm Hard Drawn Copper), but various other sizes have been used in the past. See *Figure 184*.

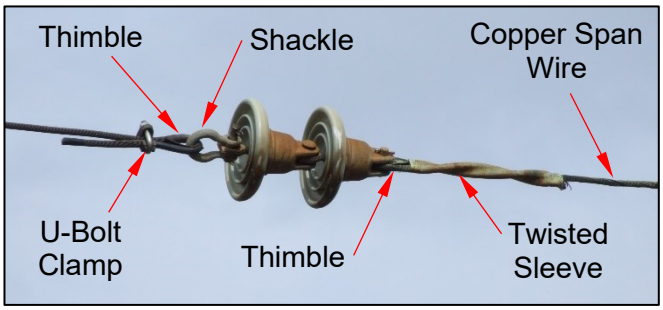


Figure 184 - Typical old cross-span insulation arrangement

There are a number of reasons for using copper span wire:

- It won't corrode (whereas galvanised steel will, in time),
- It will allow for some (stray) dc current flow in the arrangement, without causing damage to itself (of course, too much current can result in annealing which can cause the span to fail when under tension, but this is unusual).
- It can be readily adjusted, for instance to conveniently adjust the pull-off arm position and thus the contact wire stagger, depending on whether this has been allowed for in the arrangement (the use of U-bolt clamps can provide this adjustment).

Note that *steel wire* has been used to span across tracks to lock the dead (top) side of the catenary insulators in place, to limit insulator swing with radial load. It is generally not used on the live side of the OHW (possibly due to concern over corrosion of inner strands, or maybe to avoid passing dc current).

More recently, this steel wire has been replaced by lengths of galvanised steel chain links, which apparently offers more convenient installation and adjustability.

CROSS-SPAN WIRE

A cross-span wire arrangement can be employed to register the contact wires of one or more tracks. A similar span arrangement can connect to the catenary wires located above.

The wire is typically 37/1.75mm (90mm²) hard-drawn copper and is installed from a mast for the purpose of locating the catenary and/or contact wires above a relevant track. This span handles the resulting radial and wind loads from these conductors.

The 3 different cross-span situations are listed below.

One-Third Span

The span wire terminates on a mast or portal leg and registers OHW conductors for the closest track only.

Two-Third Span

The span wire crosses over the closest track to register the OHW for the 2nd track in a normal 2-track situation.

This configuration was available for both fixed-anchored and regulated OHW. See Mark 1, Type 3 / 3A regulated OHW arrangement as used in Gosford to Newcastle – *Figure 185*.

Full Span

The old fixed-anchored arrangements made great use of full span arrangements, which typically connected from one mast and crossed to the opposite mast, and was located about 300 – 500mm above contact height. This span wire allowed pull-off arms to be clipped to it where needed to register the contact wire at certain staggered positions above various tracks. It usually registered all sets of OHW along the way. See *Figure 237* further on for example.

This was particularly effective when spanning multiple (4, 6, 8 or more) tracks.

However, this approach is generally no longer used, due to the requirement for "Independent Registration" these days (unless in shunting yards or similar).

U-Bolt Clamp

The ends of copper spans typically require the wire to be bent around a copper thimble (which provides a soft buffer to protect the strands of the copper wire), and terminated with either a "twisted sleeve" (not used any more) or a pair of 10mm stainless steel "U-Bolt" clamps (called "Crosby" clamps by field staff – fitting 463/21). See *Figure 184* and *Figure 186*.

Note that only a single U-bolt clamp is shown in *Figure 184*, but a second clamp is essential these days because of the need to hold higher radial loads (due to higher catenary and contact wire tensions) and to improve reliability (through redundancy).

Twisted Sleeve

A twisted sleeve (e.g. fitting 259/2) is simply an elongated tube of soft annealed copper that is inserted over both the span wire and its return span (2 wires side-by-side). A special tool allows the tube to be twisted and, in doing so, be crushed, forming a fairly solid connection. The soft copper work hardens in the process of twisting, which helps to retain the connection. See *Figure 184* and *Figure 185*.

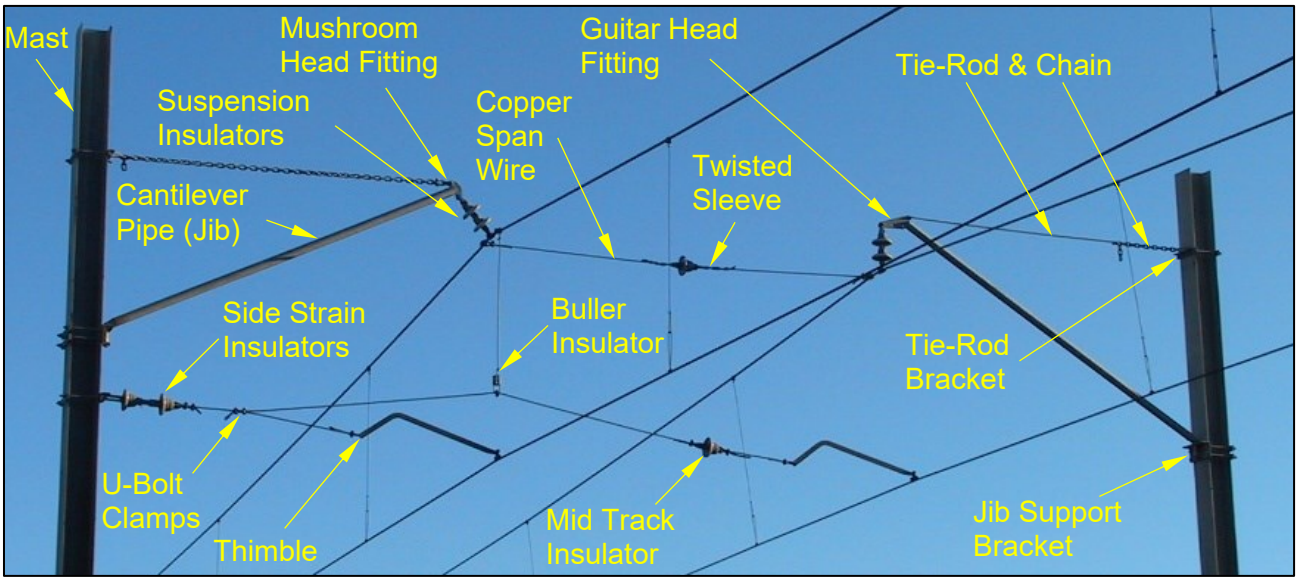


Figure 185 - Typical Cantilever components

Twisted sleeves cannot be undone and so they do not allow for convenient span adjustments, whereas the U-bolt clamps (e.g. fitting 463/21) can be readily undone, adjusted along the span and then retightened.

Often a span arrangement will have a twisted sleeve at one end (fixed) and the pair of U-bolt clamps at the other end (which is for providing local position or tension adjustments).

The current attitude is to *not use twisted sleeves*, because:

- Failures that have occurred (mostly by other electricity distributors),
- The need for the special tool and method required to install them (compared to the simplicity of the U-bolt clamp),
- They will not allow for span length adjustment, and
- The sleeve itself hides the wires over a significant distance, and although it's unlikely, this could hide problems (e.g. if steel wire were to be used, it could hide internal corrosion of the steel strands).

So, these days a pair of U-bolt clamps are installed at both ends of a span (including thimbles) without the need for the twisted sleeve.

THIMBLE

Thimbles are tear-shaped pieces of copper sheet which are formed to a "U" shape in section view, which is needed to capture the thickness of the wire as it bends around the thimble.

They are used to help protect a copper span wire when it wraps around a stainless steel pin, or through the large bare hole in a pull-off arm or the like. The thickness of the copper sheet provides a soft cushion for the hard-drawn copper strands which are already under high stress when bent tightly around a pin. See *Figure 184* and *Figure 186*.

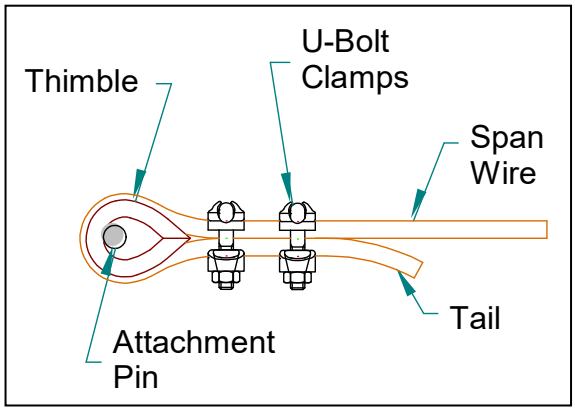


Figure 186 - Thimble

Note that smaller stainless steel thimbles have been used to terminate stainless steel wire installed in certain S&R arrangements (including recently in the compound OHW system in the Blue Mountains), as well as on some section insulators (where this wire is mainly there for side runner alignment purposes).

CATENARY SADDLE CLAMP

This 2-piece gunmetal fitting clamps around the catenary wire for the purpose of attaching a span wire or a dropper to the catenary, so as to not cause any long-term damage to the catenary itself.

Saddle clamps are available for all catenary sizes, for example the saddle clamp for 270mm² catenary wire is fitting 168/3 – see *Figure 187*.

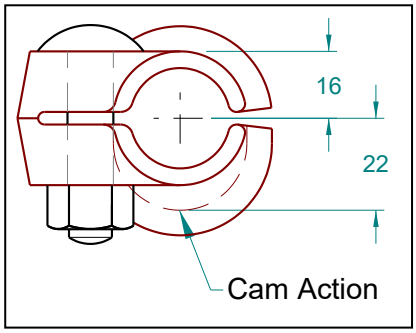


Figure 187 - Cam on Catenary Saddle Clamp

For the *span wire*, it connects by looping the span wire around the saddle clamp and tying off with 2 U-bolt clamps (463/21).

In the case of *droppers*, the solid dropper wire passes over the clamp to rest on top of it, which then becomes trapped by the clamp sides. It then takes the weight of the supported contact wire below.

This clamp offers a sacrificial interface by protecting the vital catenary outer strands from wear damage against the span wire or solid dropper wire, especially over a long period of time. Refer to the left image of *Figure 95* (much further back) for an example of the type of damage that can happen to a saddle clamp and catenary wire when things aren't ideal.

Cam Mechanism

The catenary saddle clamp is quite thick – much more than would normally be needed to prevent wear.

The thickness of this style of clamp was needed for it to take on a deliberate "cam" shape. This cam (*Figure 187*) was intended to provide some degree of fine adjustment for certain droppers, to help remove "rattlers" (droppers not supporting any contact weight) in the old fixed-anchored OHW system.

Rotating this saddle clamp (cam) provides a gradual 6mm total movement – 16mm to 22mm on *Figure 187* (i.e. ±3mm). This doesn't seem much, but with 12mm dropper increments for the older "special" droppers (*short* or *restricted* droppers), it was all that was needed (at this and/or adjacent droppers) to improve the rattling situation. A close-up view of this type of clamp is shown installed onto 2 different catenary sizes further on in *Figure 522*.

This cam adjustment came in handy, for instance, where the contact wire lowered to go under an overline bridge, and the discrete lengths of available droppers sometimes caused one or more droppers to "rattle" because they were not supporting any contact weight. In this situation the clamp could be rotated so that the cam shape takes up the rattle (the previous and next dropper could also be adjusted to help out).

The small movement in a rattling dropper is more likely to cause wear and reduce the life of the dropper (possibly affecting train-running reliability).

Note that the catenary saddle clamp is no longer needed for the newer dropper arrangements.

TURNBUCKLE

A turnbuckle installed in a cross-span can *adjust* 2 things:

- The *tension* in the cross-span wire (if connected to something solid at each end, such as the span wire connected horizontally to both legs of a portal structure), and
- The lateral *position* of a fitting, such as moving the pull-off arm to change the contact stagger.

The amount of sag in the cross-span is sensitive to the tension in this wire, so turnbuckles are often employed to adjust for minimal sag in this span in a controlled way (without overstressing other parts).

The 2 main types of turnbuckles in use today are:

- *Fitting 436/30* – has a maximum tensile rating of 13kN. It uses 16mm diameter stainless steel pins at both ends, and is used primarily for *pull-off arrangements*.
- *Fitting 436/31* – has a higher maximum tensile rating of 54kN. It uses 19mm stainless steel pins at both ends, and is used to adjust *catenary* or *contact tension* or *position*.

When using these turnbuckles, a 3:1 safety factor needs to be applied to the above load ratings in the design.

When used to tension a *full* cross-span, only 1 turnbuckle is needed. The conductor radial loads in most cross-span situations, are in one direction, so this span takes these loads back to one mast. In that situation, the turnbuckle is installed on the other end of the span which does not take any resultant conductor radial loads, and it is simply there to hold the span wire tight so it doesn't sag too much. Installing it at this remote end means that any turnbuckle adjustments to increase span tension (from time to time) will then not affect the contact stagger of any of the various connected wires, because they are set by the fixed connection at the other end of the span.

Refer to *Figure 236* further on to see a turnbuckle in a catenary cross-span example. (*Note:* Ideally the contact cross-span should have had one too for convenient adjustment of tension.)

SPREADER BAR

A pull-off vertical "spreader bar" is installed in older cross-span arrangements, as a means of forcing down the heel of a pull-off arm attached to the lower end of the bar, so that the top side of the pull-off arm can clear the horizontal span located above it. Refer to *Figure 188*.

Regularly spaced holes in the bar allow for a limited range of vertical spreading adjustment, and a U-bolt is installed into a pair of these holes to join and lock the span wire in place.

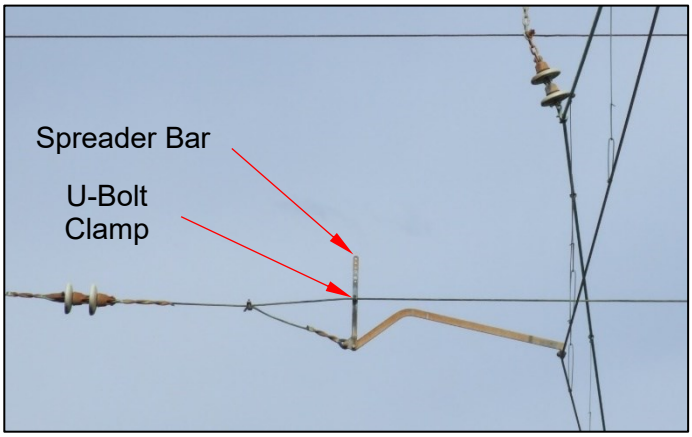


Figure 188 - Pull-Off Vertical Spreader Bar

Obviously, there will be a limit on how long the spreader bar can be – too long and it can become somewhat unstable when installed (depending on span tension also).

MAST ATTACHMENT BRACKET

A variety of standard attachment brackets exist, that clamp to certain sized OHW support structures (e.g. masts, portal legs or drop verticals). They allow some form of connection to be made to support the OHW hardware.

These generic brackets include:

- *Tie-rod brackets* (the top connection of a "cantilever" arrangement),
- *Jib support brackets* (holds the bottom end of a cantilever pipe),
- *Pull-off brackets* (for registering pull-off span fittings, solid post fittings or cross-span wires, etc.).
- *Suspension brackets* (installed on a horizontal portal bridge for the connecting of catenary suspension insulators, etc.),

Over considerable time, they have been designed for all sorts of structure sizes (both imperial and metric sizes), to attach to various standard (and non-standard) steel structures. The most common structure sizes are 150, 200, 250 and 310mm, in UC and SHS sections. Some brackets attach to double-channel portal structures and some to sections welded together with mild steel angles and plate.

Refer to *Figure 185* for some of these brackets.

INSULATED STOP BEAM

These devices are a "last line of defence" item. They are only rarely needed to prevent the catenary wire from coming too close to, or touching, a bridge or similar structure located above. Refer to *Figure 189*.

Ideally the OHW design for that situation should not require such an item, but if there are limited options for supporting and controlling the movement of the catenary, sometimes this device may become necessary.

So, they are only installed if the catenary is vertically close to the bridge and where it may be possible for the catenary to be further uplifted in some way. E.g. this can occur under cold temperatures in fixed-anchored OHW, with the catenary already close to the bridge above.

They force the catenary to keep its distance from the bridge under the worst case.

Insulated stop beams consist typically of an insulated rod of permali beam (special laminated timber) or fibreglass rod, supported at both ends by fittings that attach to the bridge.

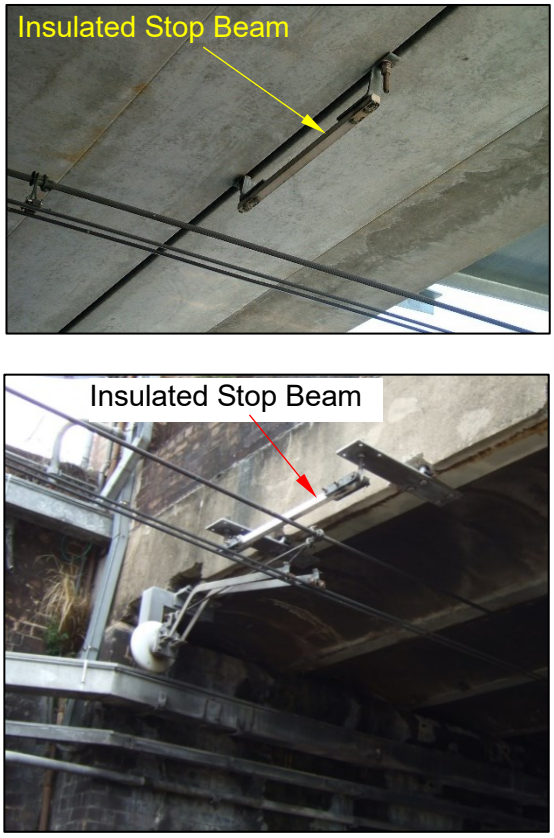


Figure 189 - Insulated Stop Beams

The beam needs to be strong and stiff enough to resist any upward catenary movement, but not cause any damage to the outer strands of the catenary wire if and when contact occurs.

Note that they are not designed to be in constant connection with the catenary – they are only there in case the catenary temporarily lifts to a level which would otherwise encroach electrical clearances to the bridge.

3.2.0.4 Configuration

S&R arrangements have one side that is installed on some support structure (such as a steel mast or tunnel lining), and the other side attaches to the OHW catenary and/or contact wires.

They include the following basic configuration arrangements (with corresponding subsection numbers), and are discussed in detail over the following main sections:

1. Cantilevers
2. Portal Suspensions
3. Polygons
4. Pull-offs
5. Bridge arrangements
6. Tunnel arrangements
7. Auxiliary Feeders

The OHW term "suspension" generally applies to an arrangement that supports or "suspends" the catenary wire from above, i.e. the catenary hangs under its support insulators.

A typical support & registration arrangement uses a set of suspension insulators – 1 or 2 disc insulators – in series with a catenary suspension clamp fitting holding the catenary wire. With this configuration, the insulators allow the catenary to swing laterally in response to any static radial load and dynamic wind load. In this way there is virtually no risk that the catenary wire can fatigue at the connection point.

Alternatively, a post type insulator supporting the catenary from above also makes up a suspension arrangement. There is no allowance for wire movement in this situation, unless special roller fittings or similar are employed.

Table 20 and *Table 21* list the main *regulated* and *fixed-anchored* OHW support & registration arrangements (respectively) as identified in the Technical Maintenance Plan. Note that *Table 20* is not necessarily a complete or up-to-date listing of all available OHW S&R systems, and this may be true of some equipment for new electrification works. Instead, please refer to *Section 8.2* which has a copy of the "Standard OHW Arrangements for New Electrification". This list is meant to be updated from time to time to reflect the current situation, and is available on the internet (or at least it was up until 2014).

TMP Code	Equipment Name	Made By	Drawing No.
EP-08-11-00-00	**Regulated OHW Support & Registration Arrangements**		
EP-08-11-01-00	*Liverpool-Glenlee Cantilever - Type 1, 1A, 2*	*RailCorp*	*C/77487 sh.1, 2*
EP-08-11-02-00	*Liverpool-Glenlee Cantilever - Type 2A*	*RailCorp*	*C/77487 sh.2*
EP-08-11-03-00	*Liverpool-Glenlee Cantilever - Type 3 & 3A*	*RailCorp*	*C/77487 sh. 3*
EP-08-11-04-00	*Liverpool-Glenlee Cantilever - Type 1G, 2G*	*RailCorp*	*C/77614*
EP-08-11-11-00	*Mark-1 Cantilever Arrangements - Types 1, 1A, 2*	*RailCorp*	*C/82387 sh. 1,2*
EP-08-11-12-00	*Mark-1 Cantilever Arrangements - Type 2A*	*RailCorp*	*C/82387 sh. 2*
EP-08-11-13-00	*Mark-1 Cantilever Arrangements - Type 3*	*RailCorp*	*C/82387 sh. 3*
EP-08-11-14-00	*Mark-1 Cantilever Arrangements - Type 3A*	*RailCorp*	*C/82387 sh. 3*
EP-08-11-15-00	*Mark-1 Cantilever Arrangements - Types 1G, 2G, 1GA, 2GA*	*RailCorp*	*K/82390 sh. 1, 2*
EP-08-11-16-00	*Mark-1 Cantilever Arrangements - Type 3G*	*RailCorp*	*K/82390 sh. 3, 4*
EP-08-11-17-00	*Mark-1 Cantilever Arrangements - Type 3GA*	*RailCorp*	*K/82390 sh. 3, 4*
EP-08-11-18-00	*Mark-1 Cantilever - Suspension Arrangements*	*RailCorp*	*D/82389 sh. 27A - 3*
EP-08-11-19-00	*Mark-1 Cantilever - Pull-off Arrangements (Catenary & Contact)*	*RailCorp*	*D/82389 sh.5A-2, 5A-3, 5A-5*
EP-08-11-21-00	*Mark-2 Cantilever - Type 1 & 2*	*RailCorp*	*B/85084 sh. 1A*
EP-08-11-22-00	*Mark-2 Cantilever - Type 1A & 2A*	*RailCorp*	*B/85084 sh. 1A, 3A*
EP-08-11-23-00	*Mark-2 Cantilever - Type 1 & 2 on Dropper*	*RailCorp*	*B/85084 sh. 2A*
EP-08-11-24-00	*Mark-2 Cantilever - Type 3*	*RailCorp*	*B/85084 sh. 4A*
EP-08-11-25-00	*Mark-2 Cantilever - Type 1S & 2S*	*RailCorp*	*B/85084 sh. 5*
EP-08-11-26-00	*Mark-2 Cantilever - Type 3S*	*RailCorp*	*B/85084 sh. 6*
EP-08-11-27-00	*Mark-2 Cantilever - Type 3A*	*RailCorp*	*B/85084 sh. 7*
EP-08-11-28-00	*Mark-2 Cantilever - Type 1G & 2G*	*RailCorp*	*B/85084 sh. 8*
EP-08-11-29-00	*Mark-2 Cantilever - Type 3G*	*RailCorp*	*B/85084 sh. 9*
EP-08-11-30-00	*Mark-2 Cantilever - Type 1GS & 2GS*	*RailCorp*	*B/85084 sh. 10*
EP-08-11-31-00	*Mark-2 Cantilever - Type 3GS*	*RailCorp*	*B/85084 sh. 11*
EP-08-11-35-00	*Pull-off Arrangement - General Type 3*	*RailCorp*	*B/87104 sh. 2*
EP-08-11-41-00	*Overline bridge Arrangements*	*RailCorp*	*EE/85557*
EP-08-11-61-00	*Insulated Stop Beam Arrangement*	*RailCorp*	
EP-08-11-71-00	*Tunnel Arrangements - Typical Mark-0*	*RailCorp*	
EP-08-11-75-00	*Tunnel Arrangements - Typical Mark-1*	*RailCorp*	*A/85367 sh. 1 etc.*
EP-08-11-76-00	*Tunnel Arrangements - Tunnel Cantilever*	*RailCorp*	*A/85367 sh. 1,2, etc.*
EP-08-11-77-00	*Tunnel Cantilever - Coalcliff Tunnel*	*RailCorp*	*B/85661*
EP-08-11-78-00	*Tunnel Cantilever - Typical Mark-2 (Chatswood)*	*RailCorp*	*EL 0189498*
EP-08-11-79-00	*Tunnel Cantilever - Typical Mark-3 (North Sydney)*	*RailCorp*	*EL 0357173*
EP-08-11-91-00	*Contact Only Support - Type 1 (Tangent Track)*	*RailCorp*	*C/82356*
EP-08-11-92-00	*Contact Only Support - Type 2 (Tight Curves)*	*RailCorp*	*C/82356*

Table 20 - Regulated OHW Support & Registration arrangements

(TMP Code	Equipment Name	Made By	Drawing No.
EP-08-12-00-00	**Fixed Anchor OHW Support & Registration Arrangements**		
EP-08-12-01-00	*Portal Suspension Arrangements - Types 1, 2, 3, 4*	*RailCorp*	*C/75075 sh. 1,2,3,4*
EP-08-12-03-00	*Hornsby/Gosford Arrangement*	*RailCorp*	*B/73402, C/73945, B/73891*
EP-08-12-05-00	*BICC (Compound) Portal Suspension Arrangements*	*BICC*	*C/74670, C74671, C/74672, B/74677, C/74678*
EP-08-12-07-00	*New Compound System - Types 1 & 2 Suspension Arrangements*	*RailCorp*	*B/88560 sh. 1,3.*
EP-08-12-08-00	*New Compound System - Type 3 Suspension Arrangements*	*RailCorp*	*B/88560 sh. 2,4.*
EP-08-12-11-00	*Portal Susp. - Mortdale/Sutherland - Types 1, 1A, 2*	*RailCorp*	*B/88424 sh. 1,2.*
EP-08-12-12-00	*Portal Susp. - Mortdale/Sutherland - Type 2A*	*RailCorp*	*B/88424 sh. 2*
EP-08-12-13-00	*Portal Susp. - Mortdale/Sutherland - Type 3*	*RailCorp*	*B/88424 sh. 3*
EP-08-12-21-00	*Cantilever Arrangements on Wood Poles - Types 1 & 2*	*RailCorp*	*C/80276 (Blacktown-Riverstone, Clyde-Carlingford, etc.)*
EP-08-12-22-00	*Cantilever Arrangements on Wood Poles - Type 3*	*RailCorp*	*C/80276 (Blacktown-Riverstone, Clyde-Carlingford, etc.)*
EP-08-12-31-00	*Pull-off Arrangements - Types 5, 6, 7, 8 (and General)*	*RailCorp*	*C/75075 sh. 5,6,7,8*
EP-08-12-32-00	*Pull-off Arrangement on Wood Pole - Type 4*	*RailCorp*	*C/80276 (Blacktown-Riverstone, Clyde-Carlingford, etc)*
EP-08-12-36-00	*BICC (Compound) Pull-off Arrangements*	*BICC*	*C/74673, B/74674, C/74675, C/74676*
EP-08-12-37-00	*New Compound System - Types 1 & 2 Pull-off Arrangements*	*RailCorp*	*B/88560 sh. 5,6,10,11.*
EP-08-12-38-00	*New Compound System - Type 3 Pull-off Arrangements*	*RailCorp*	*B/88560 sh. 7,8,9,12,13.*
EP-08-12-41-00	*Push-off Arrangement - Mortdale/Sutherland*	*RailCorp*	*B/88424 sh. 4*
EP-08-12-42-00	*Pull-off Arrangement - Mortdale/Sutherland*	*RailCorp*	*B/88424 sh. 4*
EP-08-12-61-00	*BICC (Compound) Overline bridge Arrangements*	*BICC*	*B/74556, B/74536, B/74540.*
EP-08-12-62-00	*General Overline bridge Arrangements*	*RailCorp*	
EP-08-12-71-00	*Tunnel Arrangements - City Tunnels (and General)*	*RailCorp*	*B/24007, B/23187, C/23353, C/23473.*
EP-08-12-81-00	*BICC (Compound) Tunnel Arrangements*	*BICC*	*B/74769 sh. 1,2,3.*
EP-08-12-91-00	*Polygon Arrangements*	*RailCorp*	*E/18010 sh. 82 (e.g.)*
EP-08-12-96-00	*Contact Only Support*	*RailCorp*	*EE/27775*
EP-08-14-00-00	*Auxiliary Feeder - Support Arrangements*		
EP-08-14-01-00	*General Arrangement*	*RailCorp*	

Table 21 - Fixed-anchored OHW Support & Registration arrangements

3.2.0.5 Design Notes

Most of the components used in the variety of support & registration equipment, have a proven track record (so to speak) – built up over many decades of service – of being *robust* and *reliable*.

New technology often offers improvements and ought to be considered, provided it is appropriate and is properly designed so it doesn't cause problems sometime in the future. Some of the more recent additions, including the cycloaliphatic resin post type insulator, required rigorous testing – mechanical and electrical – before being adopted into the system (which is a normal requirement).

However, no matter how well a component has performed in the past, it still requires any new design using that component to take into account its mechanical and electrical characteristics, and not be overloaded or overstressed (respectively). This is why it's so important that all designs are independently checked for such issues & any other foreseeable problems or issues.

MECHANICAL STRENGTH

There are 5 types of forces (or combinations thereof) that are applied to the various OHW components, as seen diagrammatically in *Figure 190*:

- Tension,
- Compression,
- Torsion,
- Bending, and
- Shear.

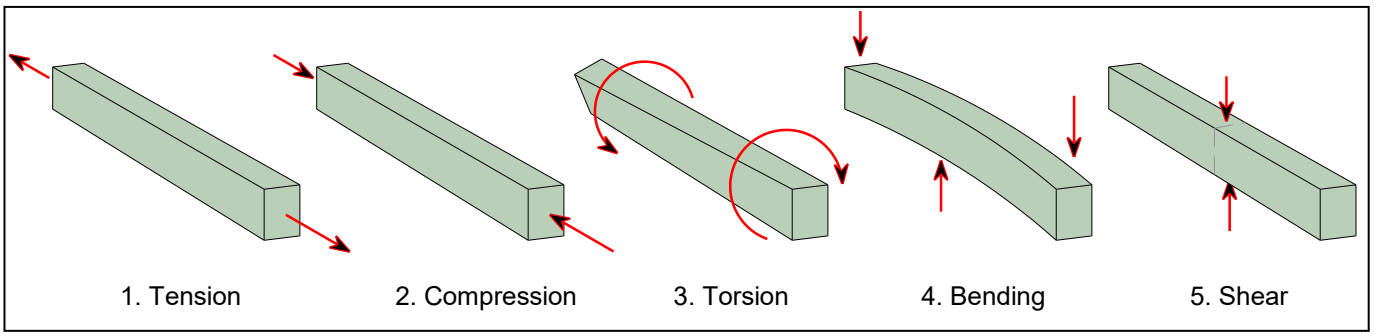


Figure 190 - The types of forces on OHW components

Because support & registration arrangements are usually highly loaded, it is particularly important during the design process that the various components are sized and checked out for these loads in their worst-case scenarios. Typically, fittings are required to have a 3:1 minimum safety factor applied, and for castings and composite insulators it's 4:1. Refer to standard EP-08000013-SP, "OHW Fittings & Materials" for details.

It is also important that the fittings are not overstressed during construction and later on during subsequent maintenance activities, and sometimes the safety factor helps in this regard (although the situation should always be checked out for strength beforehand).

OHW LOADINGS ON S&R ARRANGEMENTS

OHW support and registration equipment at a particular location will need to deal with the various mechanical loadings imposed on it by the OHW conductors, including:

- ***Radial loads*** – these are lateral loads due to the tensioned catenary and contact wires changing direction at that location (the staggered wire needs to follow the associated track).
- ***Wind loads*** – these are lateral loads acting onto the exposed catenary and contact wire and associated hardware under the influence of wind. The loading on the wires is taken from midway between the last registration point in the previous bay, to the same point in the next bay – termed the "Wind Span", as depicted in *Figure 191* (contrasted with *weight span* shown above).
- ***Weight loads*** – these are vertical loads resulting from the weight of the catenary and contact wires and all other associated hardware (droppers, in-span feeders, SIs, etc). This load includes all such hardware from the *catenary low-point* in the bay before the catenary support location, to the same point in the bay after the support location. This distance is termed "Weight Span", as shown in *Figure 191*.

The "Radial Load" is determined by the amount that the catenary or contact wire changes horizontal direction at that S&R location, and the value of the radial load is proportional to the conductor tension. The contact radial load is transferred to the pull-off arm, and the catenary radial load is taken by the catenary suspension insulator arrangement (often causing it to swing laterally – see next heading).

The "Wind Span" is the distance from midway between the points where the catenary and/or contact wires are registered, in the preceding and next bays. Here, the horizontal wind load acting on the contact wire between these midway locations is taken by the pull-off arm, and the corresponding wind load in the catenary is taken by the catenary suspension insulators (along with the static radial load). This extra loading, in addition to the radial load, can cause these insulators to momentarily change their amount of lateral swing.

When designing OHW, each catenary and contact wire will have its own Wind Load Factor, which is calculated for the maximum wind speed. E.g., from *Table 6* the Dynamic Wind Load factor for a 270mm² catenary wire is 25.0N/m, and for a 137mm² contact wire is 12.84N/m. Multiplying the Wind Span by this number gives the wind loading for that length of exposed conductor.

The "Weight Span" is the distance from catenary low-point to catenary low-point. Here, the catenary is important (not the contact and other hardware) because all the conductor hardware is supported by the catenary wire, i.e. the weight of all the conductors, droppers, in-span feeders, etc. between the 2 low points is supported by the catenary suspension insulators at this S&R location.

Table 6 includes the Weight of the various individual catenary and contact wires. *Table 7* includes the System Weight W_{System} for the various OHW systems.

E.g. the standard OHW system No.2 (270mm² catenary / 2x137mm² contacts) has W_{System} = 51N/m, so a cantilever holding a 60m weight span would support 3,060N.

Note that the Wind Span and Weight Span need not be the same distances. For example, if the catenary height was reduced at a support location, as shown in "b) Lowered Catenary" in *Figure 191*, then its weight load would be less. This is because when a catenary wire is lowered, more of its weight gets supported at the other end of each bay.

Note also that the track grade affects the catenary low-point and thus the weight span figure. This is because the catenary sags (under gravity) relative to a common horizontal reference (and not the track).

If there's an intermediate "Pull-Off" location in a bay (which simply holds the catenary and/or contact wires in a horizontal position), then this can dramatically reduce the wind span figure.

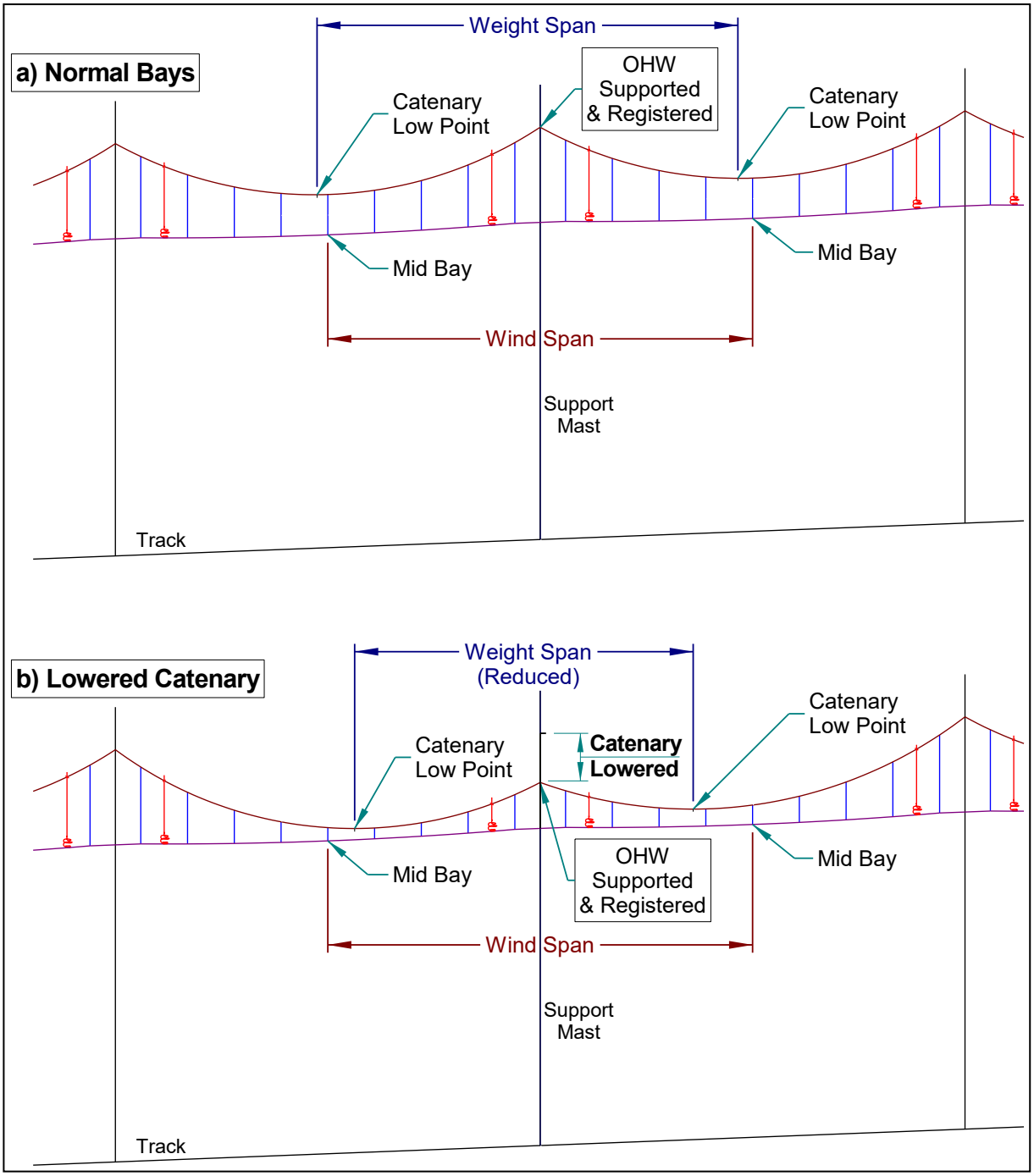


Figure 191 - Conductor loads transferred to S&R arrangement on Mast

INSULATOR SWING

Insulator swing applies to the twin suspension insulators as shown in *Figure 192*.

Swing is defined as the amount of rotation that these insulators undergo due to the combined effect of catenary system weight (vertical) and catenary radial (horizontal) loads. For OHW design work, it is important to calculate the amount of horizontal swing ("H-Swing") and vertical swing ("V-Swing"), as shown in *Figure 193*.

Note that there are some locations in Sydney's OHW system that include an additional 3rd insulator, which increases the string length by a further 150mm approx.

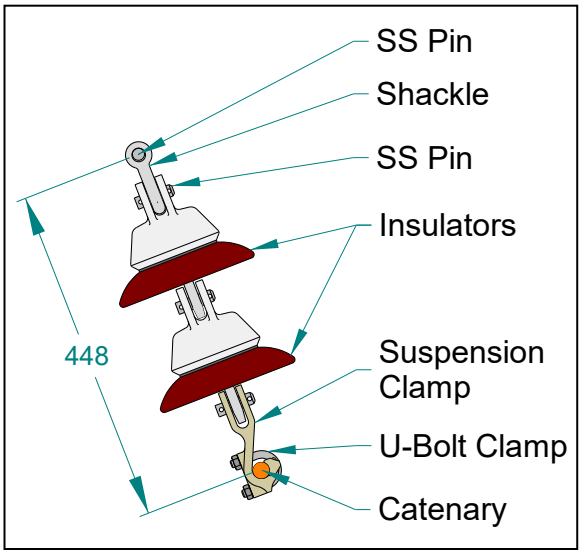


Figure 192 - Catenary Twin Suspension Insulator arrangement

Insulators that are free to rotate have both good and bad outcomes.

The Good ...

There's very little stress on the insulator itself – mostly only tensile loading along its axis, i.e. no bending, cantilever or torsional stresses. As such, the catenary, insulators and attachment hardware are unlikely to fatigue over time, and this has been validated virtually since the 1920s, provided the various components are allow to pivot relative to each other. (Note that the twin-link fitting for twin catenary can add a degree of bending, etc.)

The Bad ...

The insulator swing needs to be taken into account in each S&R instance.

- *Horizontal swing* influences the lateral make-up of the support (including the horizontal top chain length).
- *Vertical swing* influences the height of insulator attachment (e.g. tie-rod height).

Notes:

- The longer the insulator string length, the greater these horizontal and vertical offsets become. This happens when incorporating a 3rd insulator (adding 150mm), or by using a significant length of chain on the dead side as used in some "Suspension" arrangements.
- Simple trigonometry is used to calculate the horizontal and vertical components, based on the resulting catenary radial load and system weight load combination (respectively).
- Situations with very low weight spans can result in large insulator swings from vertical.

Provided the input information is correct, the CCalc computer program determines this swing at each location and accurately takes it into account for each cantilever calculated by it.

The amount of vertical swing, or changes to said, can lead to clearance issues to any objects above, e.g. the underside of a bridge.

The situation in a *fixed-anchored system* is made worse because the wire tension changes with temperature, and this can lead to altered insulator swings – more swing with more radial load (cold temperatures) and less swing with less radial load (hot temperatures).

Figure 193 shows the *H-Swing* and *V-Swing* components as a function of temperature (tension → radial load) – here shown for hot (55°C), normal (21°C) and cold (0°C) temperatures.

The *change* in insulator swing can be a problem that should be addressed during the design stage. This change sometimes translates into *reduced catenary clearances* to bridges (cold weather) and/or *lower contact height* (hot temperatures), and these situations, if they exist, should be properly checked out during design. Obviously the shorter the insulator string length, the better in terms of these horizontal and vertical components.

A good example of this type of problem happens inside tunnels. Here, the contact wire height is usually uniformly low (to fit inside the tunnel), and any reduced catenary swing will then lower the already low contact wire even more. Also, there may be structures located above the catenary such as at underground stations, so under higher (cold) tensions the reduced catenary clearance needs to still be above the minimum electrical clearance required in such situations. The needed calculations can be tricky during design – at every suspect location.

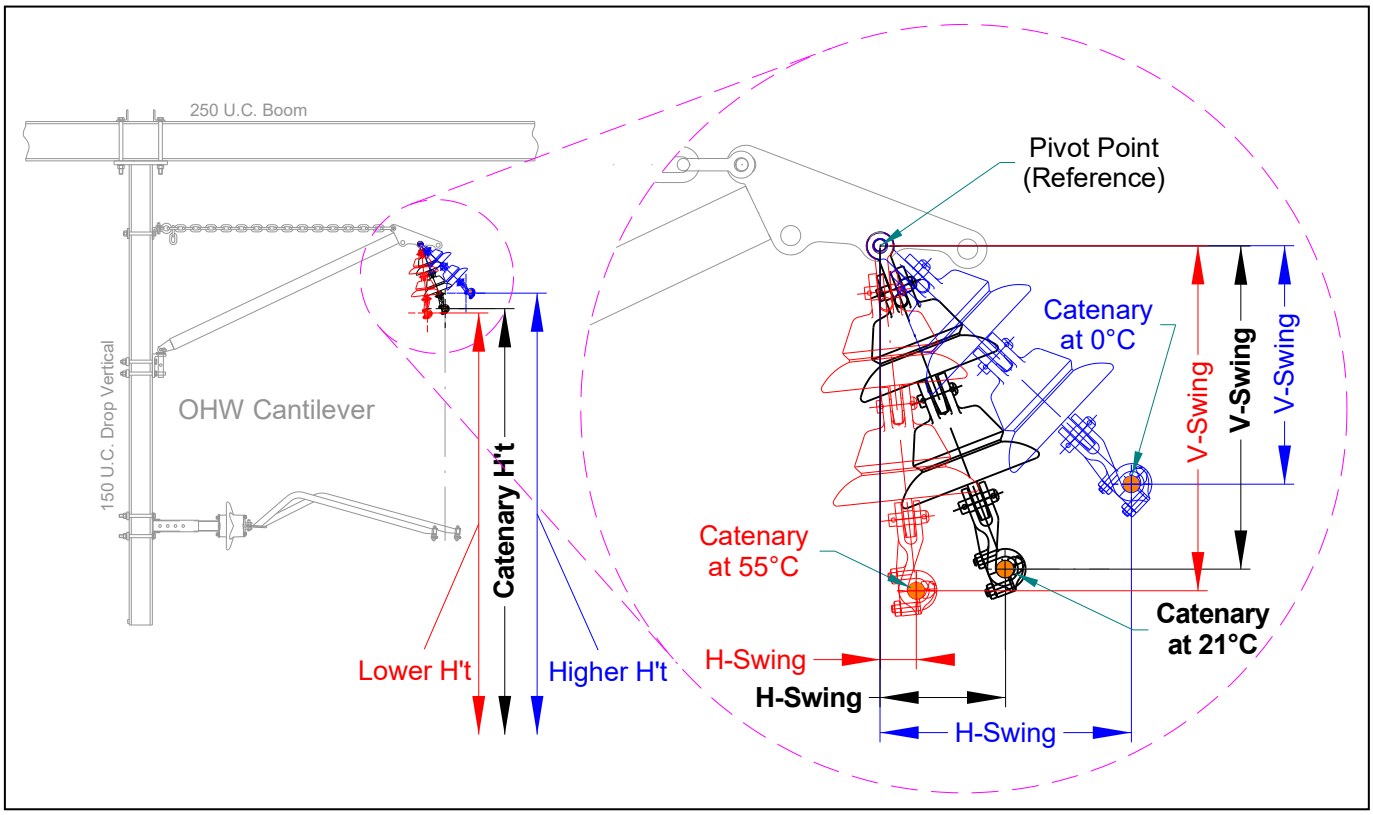


Figure 193 - Change in Fixed-Anchored insulator swing with temperature

The horizontal direction of the swing (from vertical) conveniently tells the direction of the radial load – a swing away from the support structure is +ve, and back towards the structure is -ve. So, the above figure has +ve radial load.

There is a distinct contrast between the catenary suspension insulator arrangement (above) and the catenary being supported by a post type insulator arrangement as shown in *Figure 194*. The latter is solid and does not allow the catenary to move laterally, so the radial load and wind load have no effect on the catenary wire's position. Having no insulator swing can be advantageous, but it can also cause substantial bending stresses on the insulator itself (which need to be assessed as suitable in each highly loaded case).

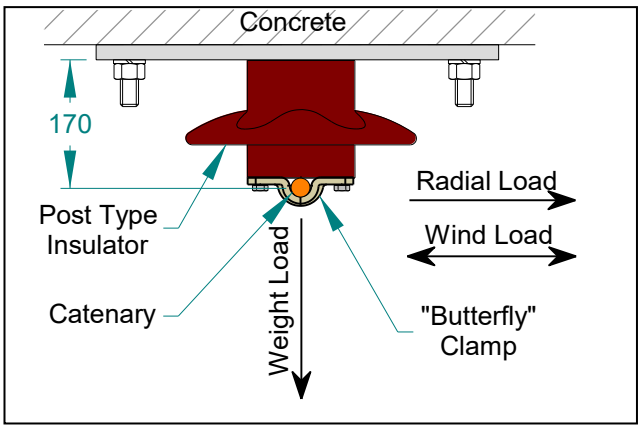


Figure 194 - Catenary supported by Post Type Insulator

Fortunately, most recent OHW designs inside tunnels use predominantly post type insulators. But even so, there are areas of higher headroom where insulator strings need to be used (to keep the catenary height low), including at underground stations and at tunnel boring machine entrance and exit shafts.

Figure 194 shows a typical post type insulator arrangement inside a flat-ceiling tunnel.

Note that if the insulator is mounted on a steel plate which is installed flush with the ceiling as shown in this figure, then the upper 4 insulator attachment set screws need countersink heads for a flush connection with the ceiling. Also, there may need to be a small space allocated for installing secondary insulation for bonding considerations in certain circumstances.

HEEL HEIGHT

At a pull-off arm, "heel height" is the vertical distance from underside of the contact wire to either:

- The centre of the arm's pivot pin, if the arm pivots vertically – see *Figure 195 (a)*, or
- The underside of the arm attachment, if it pivots horizontally– see *Figure 195 (b)*.

The heel height value can vary, but is typically about 100mm for low contact radial loads, and 50mm for high radial loads, assuming all arms are placed in tension. (Sometimes arms in compression have been given more heel height, e.g. 200mm for Mark-1, Type 1A cantilever, but this can cause some problems and is no longer acceptable practice.)

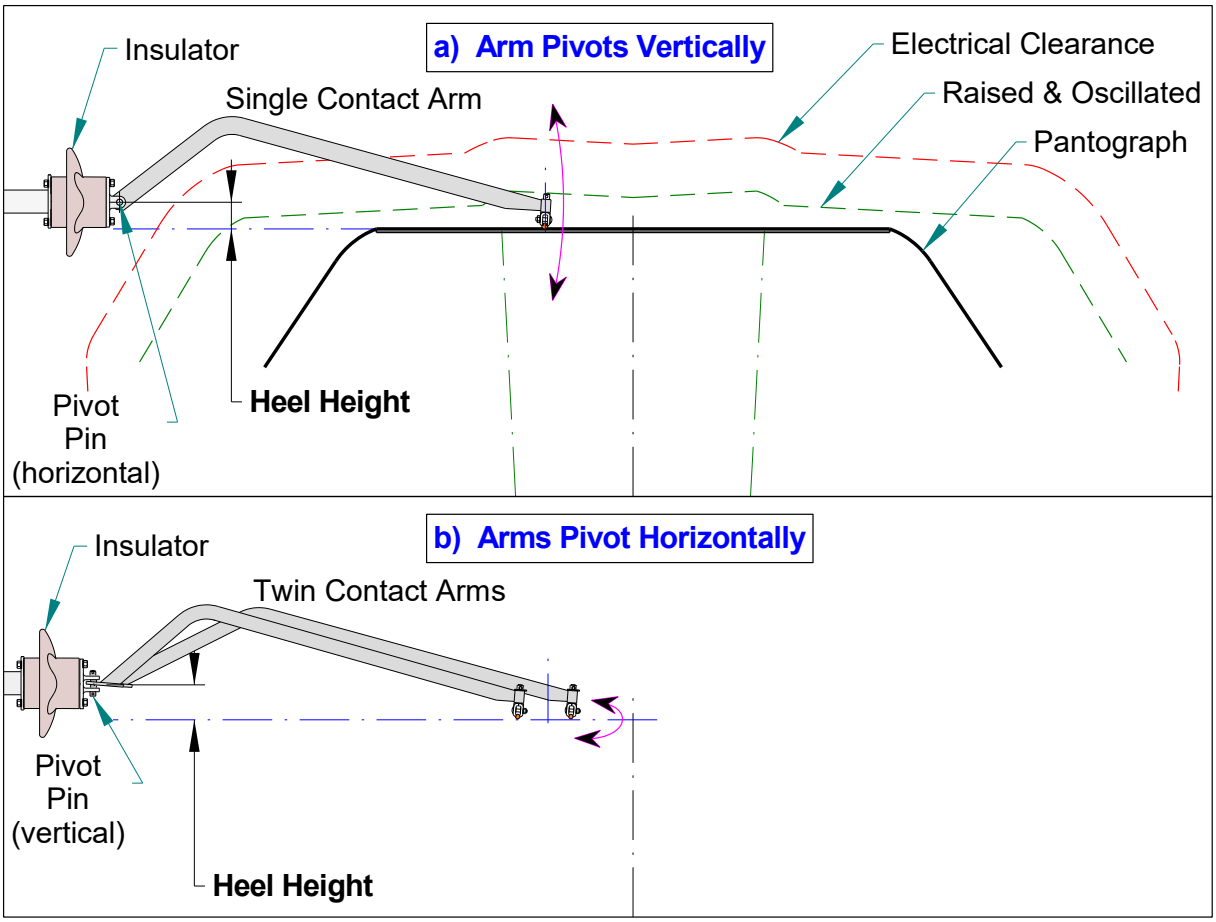


Figure 195 - Heel Height

So, why is heel height important? I understand there are at least 2 reasons for providing some heel height at a pull-off arm:

- It can give a little more *passing clearance* to the pantographs. This is the most obvious and common understanding, however it's probably not the most important reason, because (apart from straight arms) the shape of the arm and its length should give sufficient clearance to the edge of a raised & oscillated pantograph at speed in most situations, e.g. as indicated in *Figure 195 (a)*.
- It gives the contact wire better *compliance* for improved pantograph performance at speed (see next subheading). This is likely the most important reason for adding heel height to a pull-off arm in the majority of cases.

Figure 196 shows a *mid-bay pull-off* location that positions the contact wire using a pull-off arm pivoting, from a *solid* insulator channel post (which is not intended to move vertically or horizontally). This would normally be for a low radial load situation, typically as a consequence of the *adverse condition* – refer to *Section 5.1.23.8*, *Adverse Condition* for more.

At *cold temperatures*, in a fixed-anchored OHW system the catenary tension increases and its sag reduces. This causes the contact wire to rise towards mid-bay, and by a relatively large amount – about 300mm as shown (depending on bay length, catenary virtual span, etc.).

Refer to *Figure 24 (a)* further back, to appreciate the large amount of contact wire rise and fall at mid-bay with temperature, which is mostly controlled by the catenary sag.

In this case, there is some benefit to increasing the design heel height (shown here as 75mm), so as to not cause the pantograph to collide with the uplifted pull-off arm. Fortunately, the cold contact wire tension is huge (bar tight), which should be effective in eliminating any additional uplift as each pantograph passes through.

Under *hot conditions* the reverse happens to the contact height – it is lowered as the catenary now sags more (also by about 300mm in this scenario). Unfortunately, that would lead to a heel height of a huge 375mm!

So, in this fixed-anchored example, the amount of heel height will be a trade-off to suit the extremes of contact wire height, as well as pull-off arm to pantograph clearance (when cold). The somewhat large changes in sag are due to the need to have a large catenary virtual span.

Note that, if this was a catenary *support* location instead of a mid-bay *pull-off* location, the catenary height cannot change by much, and so the contact height also does not alter by much, meaning the heel height also changes very little with temperature – all good.

So, special care is needed in very long bays with mid-bay pull-off situations in *fixed-anchored OHW*, because the effect on heel height in *Figure 196* can be quite dramatic.

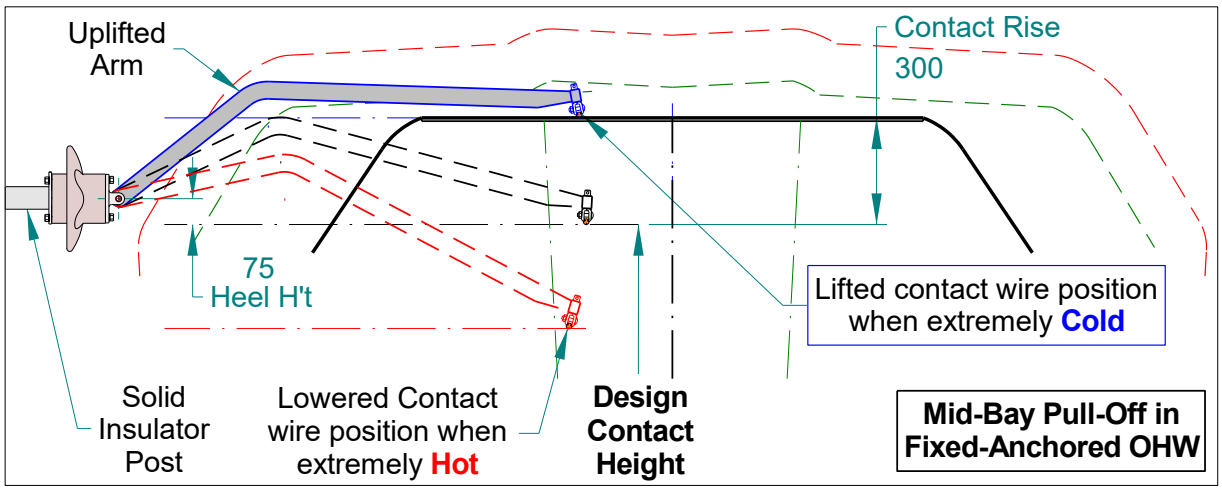


Figure 196 - Heel Height needed for pantograph clearance (Fixed-Anchored OHW)

Note that using longer pull-off arms can sometimes help improve the clearance problem when cold, from what's shown in this figure.
Also, if the Adverse Condition allows, using a Type 3 span back to the mast would help, by allowing the heel end of the arm to rise and fall by a proportional amount to the contact wire height movement, to gain better pantograph clearances than that shown in this figure.

Figure 197 is intended to demonstrate how a *straight arm* holding a contact wire with virtually no radial load (on straight track) but with a *large heel height*, can cause this wire to rise if any decent radial load were to be applied to the contact wire. In a sense, it's the extreme case of what "compliance" can generate (see below section).

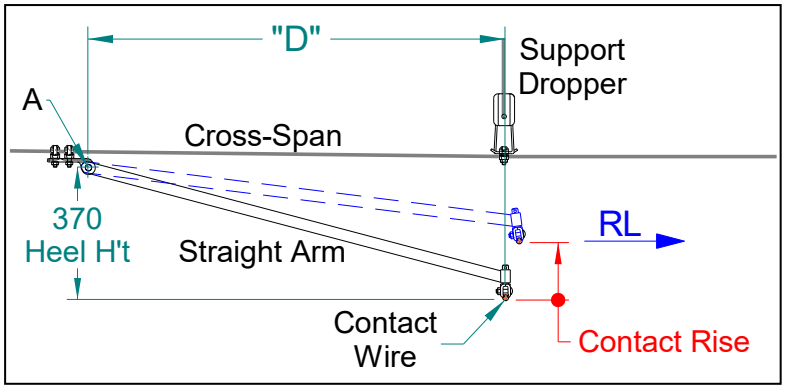


Figure 197 - Large Heel Height problems with Radial Load

To be in equilibrium, the sum of the moments about the heel of arm at "A" must be zero. So,

$$\text{Radial Load} \times \text{Heel Height} = (\text{Arm Weight} + \text{Contact Wire Weight}) \times D$$

Heel height is a *variable* in this situation. Increasing the contact radial load tends to reduce this heel height and lift the contact height, but at some point, this is counterbalanced by the additional contact wire weight needing to be supported as this wire moves upwards. However, a pantograph passing through with its 130N of upward force, will make the contact wire rise even more (albeit temporarily).

So, the situation must not allow so much pantograph uplift as to strike or otherwise damage something here. And, the wire dynamics with several fast pantographs passing through, should also be acceptable for reliably delivering uninterrupted power to the train.

This situation might be better understood in *Figure 198*, which is a 3-dimensional view of what's happening. This was initially drawn to model the *Mk-3 Tunnel Cantilever* arrangement supporting the catenary wire and with straight arm/s registering the contact wire/s (described in *Section 3.2.6*). However, it's similar to the above situation.

Case a) has no pull-off arm, so the contact wire simply sags between adjacent droppers (it's only about 8mm for regulated contact wire, but a lot more for fixed-anchored contact wire when hot ~ 25mm). The catenary wire is simply supported (by the tunnel cantilever).

Case b) adds the pull-off arm. With some radial load acting away from the support, the moment resulting at the pivoting heel end of the arm causes the contact wire to rise. In doing so, the contact wire is then supported over a distance, shown as $L_{(Static)}$, and this wire weight helps to limit any further contact wire rise. The overall effect is that the "Actual Heel Height" is less than it would have otherwise been without that contact weight.

Case c) is intended to show what happens when a pantograph parks underneath and pushes up with its 130N of uplift force. This force supports (is balanced by) 130N of contact wire weight (which corresponds to $L_{(Pan)}$, a distance of typically 7.7m for 193mm² contact wire, per *Figure 58*). Summing all the various moments to zero is a bit more involved, but it shows the interaction can lead to quite a lot of static uplift as well as a much reduced heel height. Both of these aspects need to be assessed for suitability (e.g. clearances) for it to be deemed acceptable for running trains. Obviously the fixed-anchored situation is the more onerous.

Wind load on the contact wire acting in sympathy with the radial load can add to this problem quite a lot, and this should also be checked out (although it's mostly not a problem in tunnels).

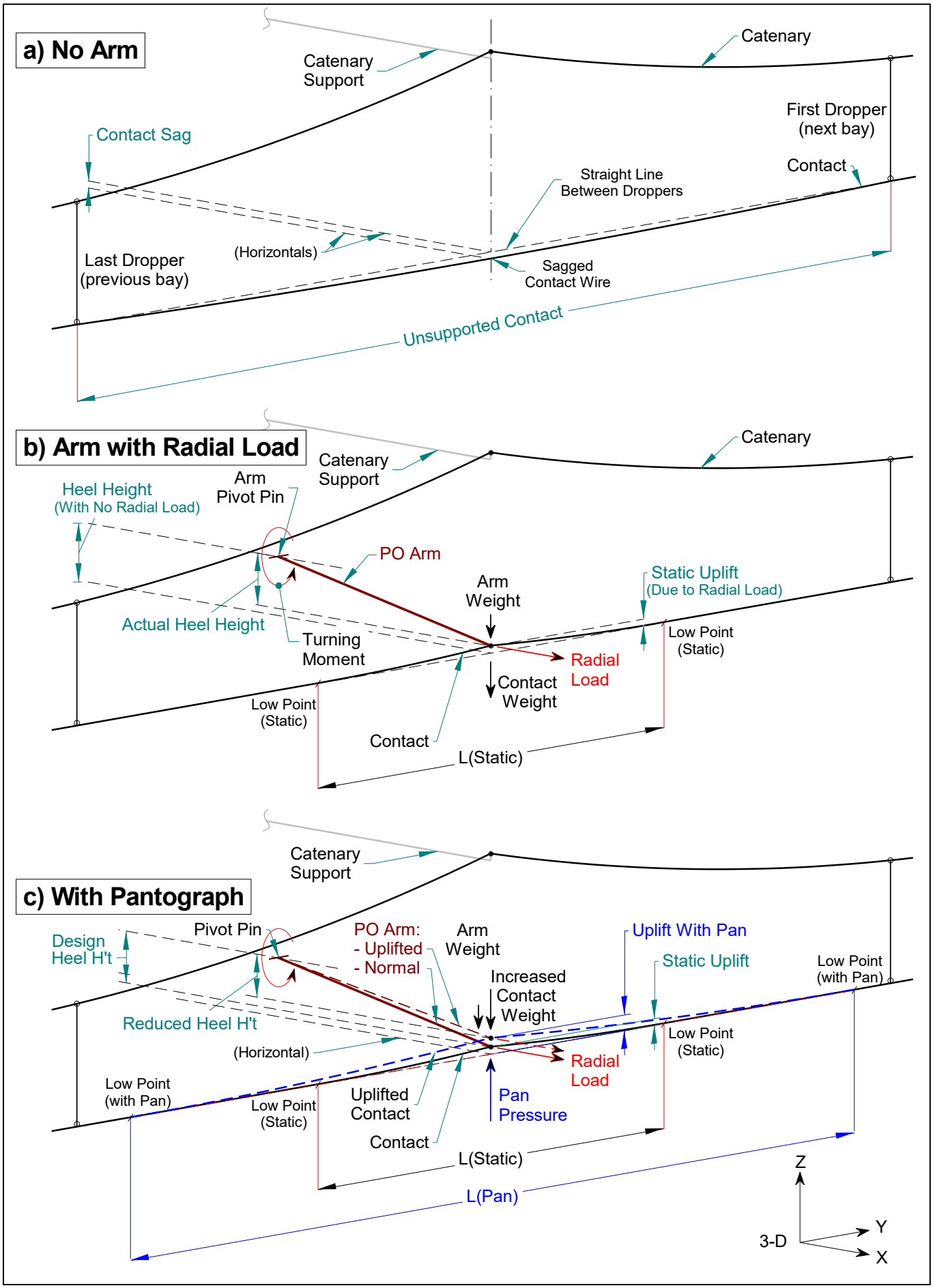


Figure 198 - Effect of Heel Height on pantograph uplift

COMPLIANCE

The term "compliance" refers to the need for the contact wire to offer a relatively constant downward pressure through each bay, to oppose the uplifting pantographs as they slide along the contact wire/s. This helps reduce the amount of contact uplift, as well as the magnitude of any oscillations throughout the bay, which in turn promotes a smoother pantograph interface with less contact arcing, especially at speed.

When travelling through the bay, the pantograph pushes up against the weight of the single or twin contact wires. At each dropper location there's a small weight of the bottom dropper half and its contact clip fitting that's added to the distributed contact weight. There may also be other localised fittings installed onto the contact wire at various locations (e.g. in-span feeders, contact full splices, etc.) that add discrete points of weight, which helps to counteract the pantograph uplift force.

However, at the support & registration location or at a mid-bay pull-off location, the pantograph will also see typically about half the weight of 1 (or 2 for twin contact) pull-off arm/s pressing down onto the contact wire/s, and the contact swivel clamp. (The remaining weight of the arm/s is supported by the pull-off arrangement at the heel of the arm.)

Adding a small amount of heel height, in combination with the contact radial load (placing tension in the arm/s), causes a turning moment about the heel end of the arm. This results in less arm weight being placed onto the contact wire at that attachment point. *This in turn means the pantograph pushes up against a more uniform contact weight in the vicinity of the pull-off arm, which is good.* This is all provided the radial load places the pull-off arm in tension – it makes the situation worse if it's in compression, which is why this is undesirable.

This end effect might sound trivial, but it can be dramatic if the weight of the arm/s does push down hard on the contact wire, causing a fairly abrupt low point and hard spot in the contact wire path. The most noticeable end effect is arcing. This can happen if a fast pantograph is suddenly forced downward when approaching the arm, and its trajectory can then tend to skip the contact wire immediately after the arm, causing a flash as the pantograph momentarily disconnects from the contact wire. It also causes accelerated contact wear in a small area surrounding the arm connection point – caused by a higher contact pressure (before and at the arm) and from arc erosion (after the arm).

This is more of a problem in a fixed-anchored OHW system when the temperature is hot, making the contact tension plummet. It causes the fast travelling pantograph to lift the contact wire much higher through the bay, and makes the arm location more of a relative *hard spot* as it again lowers down at the arm.

The dynamics of the pantograph/contact interface is quite complex, especially at speed, as there are so many variables involved. It can only be effectively analysed in the field or modelled by using sophisticated computer programs. Having more than 1 pantograph per train makes the analysis much more complex. (Sydney Trains has 4 pans per 8-car set, but fortunately they're spaced well apart, and the trains only operate at medium speed by world standards.)

So, the best performance occurs when the pantograph pushes up against a contact wire with relatively constant weight distribution throughout the various bays of a wire run. Any disruption to this uniform resistance to upward pressure can disturb the contact wire and possibly cause arcing, and introduce unwanted vertical oscillations in this wire which can propagate into adjacent bays. And the following pantographs from the same train will then need to negotiate these disturbances in the contact wire, with the last pantograph on a train wearing the brunt of activity. Ultimately the outcome can become as bad as causing intermittent loss of supply to the train (and it also looks somewhat unstable to the eye).

Example:

Figure 199 shows an unfortunate situation at Fairfield, location G29+004, where at least 2 pull-off arms had been modified to allow a catenary span connection to the top of the crank in the arm. This was probably put in place because of the reduced clearances under the footbridge (?).

This figure demonstrates a lack of awareness by the designer (if it was designed) of the importance of contact wire *compliance*. Any catenary radial and wind load in the short span, acting away from the arm, will force the pull-off arm further downwards due to the bending moment about the heel of the arm. This will make it a more obvious hard spot on the contact wire. And I suspect that significant pantograph arcing will be evident at the pull-off arm connection to the contact wire.

Even if there is very little radial load to apply downward pressure on the arm, this situation should never have been allowed to happen, and *unfortunately it can be wrongly copied elsewhere if people see it and think that it's OK, which it's not!*

The only positive thing to say here is that at least the pantographs that are manufactured these days are lighter in mass, are better equipped to trace the wire at speed, and they offer damping to quickly diminish any wire oscillations that might develop when encountering such bad situations. All these pantograph improvements will help to reduce the amount and level of arcing that would otherwise take place at these hard spots.

The better solution to this situation would have used a *raiser bracket* from the live side of the post type insulator, to take the (longer) span to the catenary at similar height as existing span (refer *Figure 254*). This would then not add to the pull-off arm downward pressure!

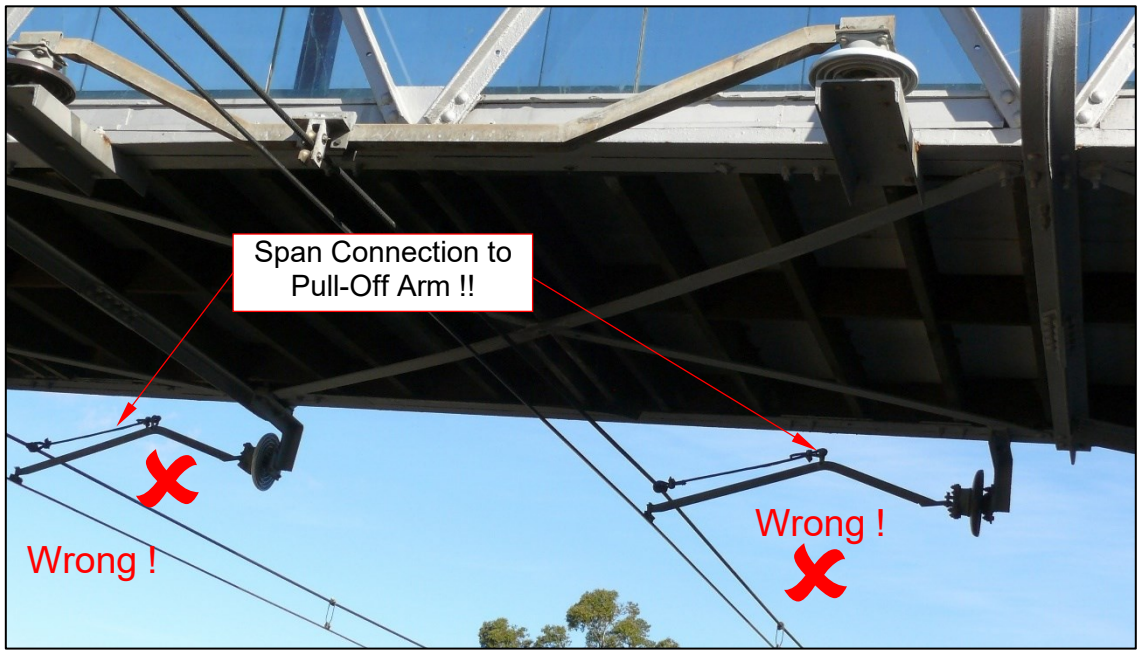


Figure 199 - Span wrongly connected to crank in Arm

SYSTEM DEPTH

This is the vertical height difference between the catenary and contact wires at the catenary support location. More precisely, this depth is from centre of catenary to the underside of new contact wire.

System depth is important because it needs to be large enough at each end of the bay to allow the bay to be droppered, given the amount of catenary sag there. Too shallow a system depth

may result in extremely short droppers, or even a situation where the catenary wire goes below the contact wire near mid-bay – horror! Too large a system depth can result in unnecessarily long droppers and may require taller support structures, which then becomes an economic issue.

The shortest dropper is just less than 100mm long, and it is unwise to design the OHW so tight as to rely on this extremely short dropper unless it's absolutely necessary.

So, the *absolute minimum system depth* in a bay is made up from:

the catenary sag (mid-bay) resulting from the bay length,
plus the shortest dropper length to be used,
minus any contact presag at mid-bay, (plus a bit, just in case).

Knowing the minimum contact height and the minimum system depth then allows the minimum catenary heights to be determined.

In regulated OHW, the system depth is currently standard at 1.5m, although it has been as large as 2.1m or so in certain areas designed many decades ago with lower tensioned catenary wires. Standard catenary and contact heights are 6.5m and 5.0m.

Fixed-anchored OHW usually has a larger system depth, to cater for the slacker catenary tension (when hot) which gives a deeper parabola than for regulated OHW (compare $T/w = 381$m to $T/w = 550$m respectively).

In certain situations, such as inside tight tunnels, the contact height remains relatively constant (low). So, the system depth at each support location depends on the catenary height, which can vary from location to location. This catenary height can depend on the curved profile of tunnel lining, catenary stagger and the catenary suspension insulator swing (which, if fixed-anchored, can unfortunately vary with temperature as shown in *Figure 193*). However, if there's a lot of insulator swing (approaching horizontal), this can result in a higher catenary which improves the system depth (although clearances would then need to be checked).

A better outcome in tight tunnels would be to use a solid post type insulator arrangement that has a shallower insulator and which also produces no swing – see *Figure 194* and *Figure 268* further on.

Generally, when inside tunnels, successive catenary support locations will not likely have the exact same catenary height. So, when designing the OHW, this necessitates drawing up a schedule of support locations and associated catenary heights for each track, resulting in the system depth determined at each location, from which droppers etc. are calculated.

Out in the open where there are less height restrictions, a standard system depth at each location can be adopted. The CCalc program can determine insulator swing and then the remaining cantilever geometry to deliver the required catenary height and system depth.

However, the catenary height can be adjusted in the design to suit all sorts of situations encountered. A good example is when leading up to a low overline bridge. Here the system depth usually needs to be progressively reduced, starting about 3 bays before the bridge, and with the shallowest depth being at or under the bridge itself. This can happen leading up to tunnels as well.

Care needs to be exercised anywhere there is a shallow system depth and with an added section insulator installed. The extra load point of the SI within the bay can sometimes result in so much additional catenary sag that the bay may not being able to be properly droppered (i.e. some of the droppers may not be short enough).

STAGGER CHANGE WITH REGULATED CONTACT WIRE

In the case of regulated OHW, the contact and catenary wires move longitudinally in sympathy with temperature changes, and in this way their respective tensions remain relatively constant.

With most regulated OHW registration arrangements, the wires are held in place using a pivoting system, either close to the mast or close to the remote end of the pull-off arm – refer to *Figure 200*. This means the arm rotates about the pivot point, and unfortunately this rotation of the cantilever with longitudinal wire movement *causes the stagger to change*. The greater the change in angle from some "normal to the track" position (at 21°C or 25°C design temperature), the greater the stagger change, and in a non-linear way.

Table 22 shows how much the contact stagger changes as the conductor temperature changes away from the design temperature (assumed 25°C in this table), and also as the distance away from the fixed anchor changes, in a regulated OHW system.

	Case 1: Typical Pull-Off on Drop Vertical			Case 2: Typical Pull-Off on Mast		
	Stagger Change with Pull-Off Arm Swing Pivot Arm Length (m) : **1.2**			Stagger Change with Pull-Off Arm Swing Pivot Arm Length (m) : **3.0**		
	Temperature			Temperature		
Distance (m)	**-5°C**	**25°C**	**60°C**	**-5°C**	**25°C**	**60°C**
0	0.000	0.000	0.000	0.000	0.000	0.000
50	0.000	0.000	0.000	0.000	0.000	0.000
100	0.001	0.000	0.001	0.000	0.000	0.001
150	0.002	0.000	0.003	0.001	0.000	0.001
200	0.004	0.000	0.006	0.002	0.000	0.002
250	0.007	0.000	0.009	0.003	0.000	0.004
300	0.010	0.000	0.013	0.004	0.000	0.005
350	0.013	0.000	0.018	0.005	0.000	0.007
400	0.017	0.000	0.024	0.007	0.000	0.009
450	0.022	0.000	0.030	0.009	0.000	0.012
500	0.027	0.000	0.037	0.011	0.000	0.015
550	0.033	0.000	0.045	0.013	0.000	0.018
600	0.040	0.000	0.054	0.016	0.000	0.021
650	0.047	0.000	0.064	0.018	0.000	0.025
700	0.054	0.000	0.075	0.021	0.000	0.029
750	0.063	0.000	0.086	0.024	0.000	0.033
800	0.071	0.000	0.098	0.028	0.000	0.038
850	0.081	0.000	0.112	0.031	0.000	0.043
900	0.091	0.000	0.126	0.035	0.000	0.048
950	0.102	0.000	0.141	0.039	0.000	0.054
1,000	0.114	0.000	0.158	0.044	0.000	0.060
1,050	0.126	0.000	0.175	0.048	0.000	0.066
1,100	0.139	0.000	0.194	0.053	0.000	0.072
1,150	0.153	0.000	0.214	0.058	0.000	0.079
1,200	0.168	0.000	0.236	0.063	0.000	0.086

Table 22 - Stagger change with temperature in Regulated OHW system

As the contact wire expands (hot) and contracts (cold), a pull-off arm moves from its ideal perpendicular position to the track at design temperature. The consequential *rotation* of the pull-off pivoting arrangement causes a small change in stagger, which gets progressively larger as the temperature gets further away from design temperature, and also as the linear distance from fixed anchor increases. (There is no wire movement at the fixed anchor.)

In addition, stagger change is also a function of the length of the pull-off arm arrangement from its *pivot point*. The longer this pull-off pivot distance is, the less stagger change will

result with temperature change, which is a good outcome – the table shows this. Compare in the table, "**Case 1**" which has a 1.2m pivot distance, with "**Case 2**" which has a 3m pivot distance. Refer to *Figure 200* which shows what the relative pivot distances look like.

The main point is that any resulting stagger at registration locations must not adversely affect *pantograph security*. This is particularly important near mid-bay with wind blowout, as this location is much less well controlled.

Two cases in *Table 22* are presented below that should help demonstrate the problem.

Case 1

A short cantilever situation on a *drop vertical* (e.g. Types 1 & 2 cantilevers) where the distance from contact wire connection to the pivot point is 1.2m (i.e. the length of a standard arm, with the pivot point at the heel of the arm). Refer to left figure in *Figure 200*.

Referring to the highlighted row of *Table 22*, for a wire distance of 1,000m from fixed anchor, there's a stagger change of 114mm when very cold and 158mm when very hot. This means that a standard 250mm stagger would be increased by these figures to 364mm and 408mm respectively! The hot stagger in particular would likely be cause for concern, since it's greater than the maximum 381mm. (Note that the hot situation would have been even worse if 21°C design temperature were to be used instead of 25°C.)

This effect should be considered during design so that the tension length would be limited to much less than 1,000m. Drop verticals are often used on tight track curves and in this case the tension length would normally be limited to much less than the maximum 1,000m length anyway. However, on tight curves the standard stagger is increased from 250mm to 300mm which can worsen the stagger change problem here. Fortunately, having twin contacts can help in this situation, with one of the 2 wires located either 75mm (for 150mm spacing) or 25mm (for 50mm spacing) closer to the centre of pantograph (and of course the other wire would be further away).

The left-hand "Plan View" inset in *Figure 200* shows the situation resulting from a wire expansion of 500mm to the left, giving in a stagger change (error) of 106mm.

Case 2

A typical cantilever situation on a *mast* where the pull-off pivot is near the face of the mast located further away at about 3m from contact wire connection. Refer to right figure in *Figure 200*.

Here the much larger pivot radius gives rise to a more forgiving stagger change than in Case 1. Referring again to the highlighted row of *Table 22*, it results in stagger changes of only 44mm and 60mm for the extreme cold and hot conditions respectively. In that case, a standard 250mm stagger becomes 294mm and 310mm respectively. These values are likely much more tolerable when trying to achieve pantograph security.

The right-hand "Plan View" inset in *Figure 200* shows the situation resulting from a wire expansion of 500mm to the left, giving in a smaller angle and stagger change (error) of 41mm, which is some 65mm better off than in Case 1 above.

As previously mentioned, the problem with stagger change is not necessarily at the support & registration location – the problem mostly occurs at mid-bay, and the changed stagger here coupled with a 130km/h wind blowing the wire out can cause the contact to venture off the pantograph and then become uncontrolled, damaging the OHW.

To compound this problem, if there's any significant permanent *contact wire stretch* over time (e.g. Gosford to Newcastle), then the arm positions will likely no longer be perpendicular to track at the design temperature. Instead they will change in the high temperature direction,

and this will make the stagger change at hot temperatures that much worse. *This is why the stagger should be routinely checked for correct position at the current temperature.*

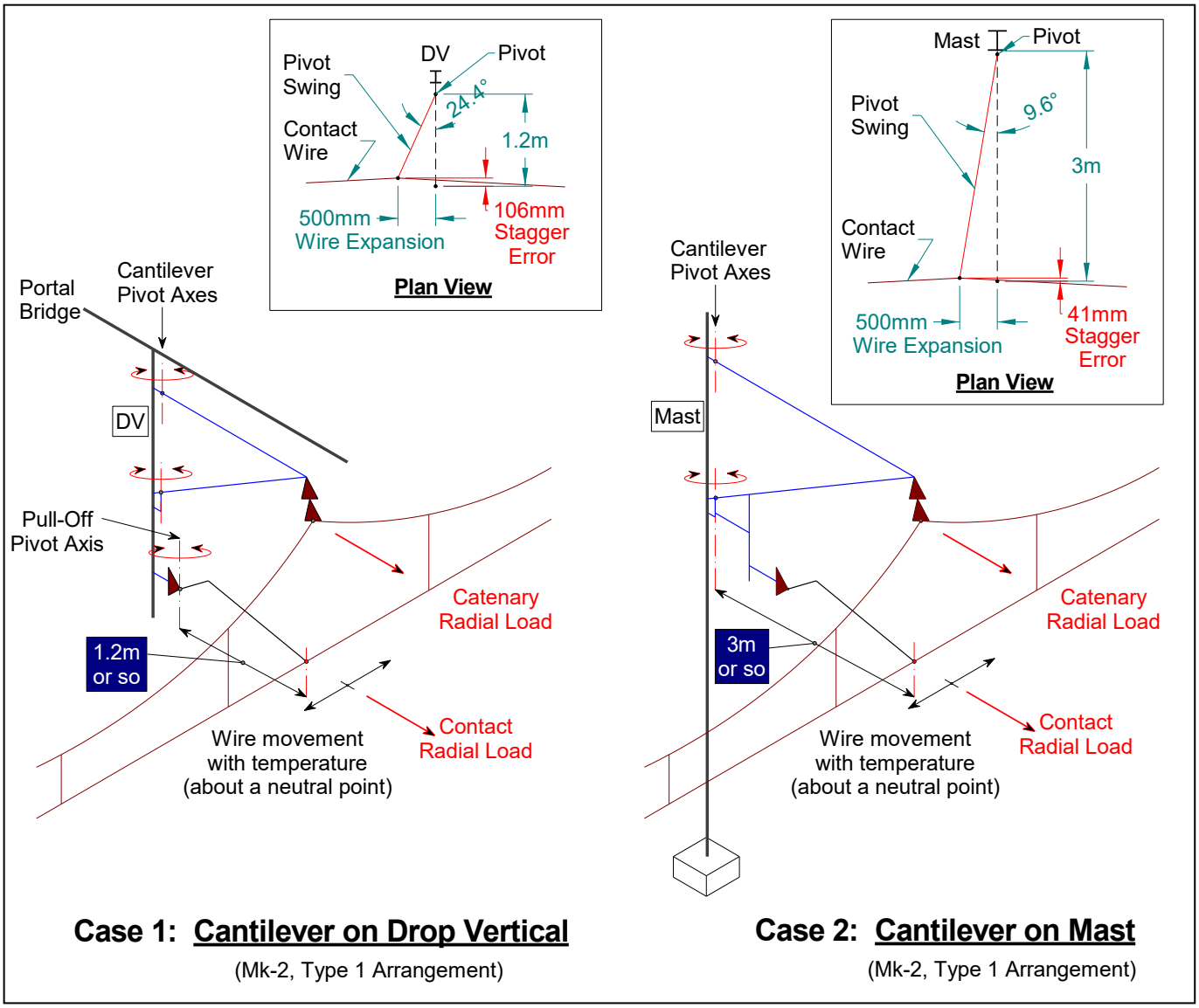


Figure 200 - Stagger error with short (left) & long (right) pivot distances

PANTOGRAPH CLEARANCES AT PULL-OFF ARMS

There are times when it is necessary to bring the pull-off arrangement close to a travelling pantograph, usually because of limited space. In design work, we usually allow at least 1.35m horizontal distance between the superelevated track and the heel of a pull-off arm in order to gain the necessary clearance to the "raised & oscillated" pantograph shape (on the pantograph gauge).

An example of a clearance problem is shown in *Figure 201*. This shows how a local adjustment – in this case, adding a pull-off raiser bracket to lift the heel of the arm 216mm higher – can inadvertently cause a pantograph clearance problem. The installers probably did this because they ran out of vertical pull-off height adjustment (located further towards the mast), and installing the raiser bracket was an easy thing to do to fix the immediate problem (and probably in a lot of situations it would have been OK). I suspect that it's likely the wrong pipe length was installed here (maybe this longer one was left over from a previous installation?), because the CCalc program would not have computed such an arrangement.

Figure 201 - Pull-Off Raiser Bracket clearance uncertainty

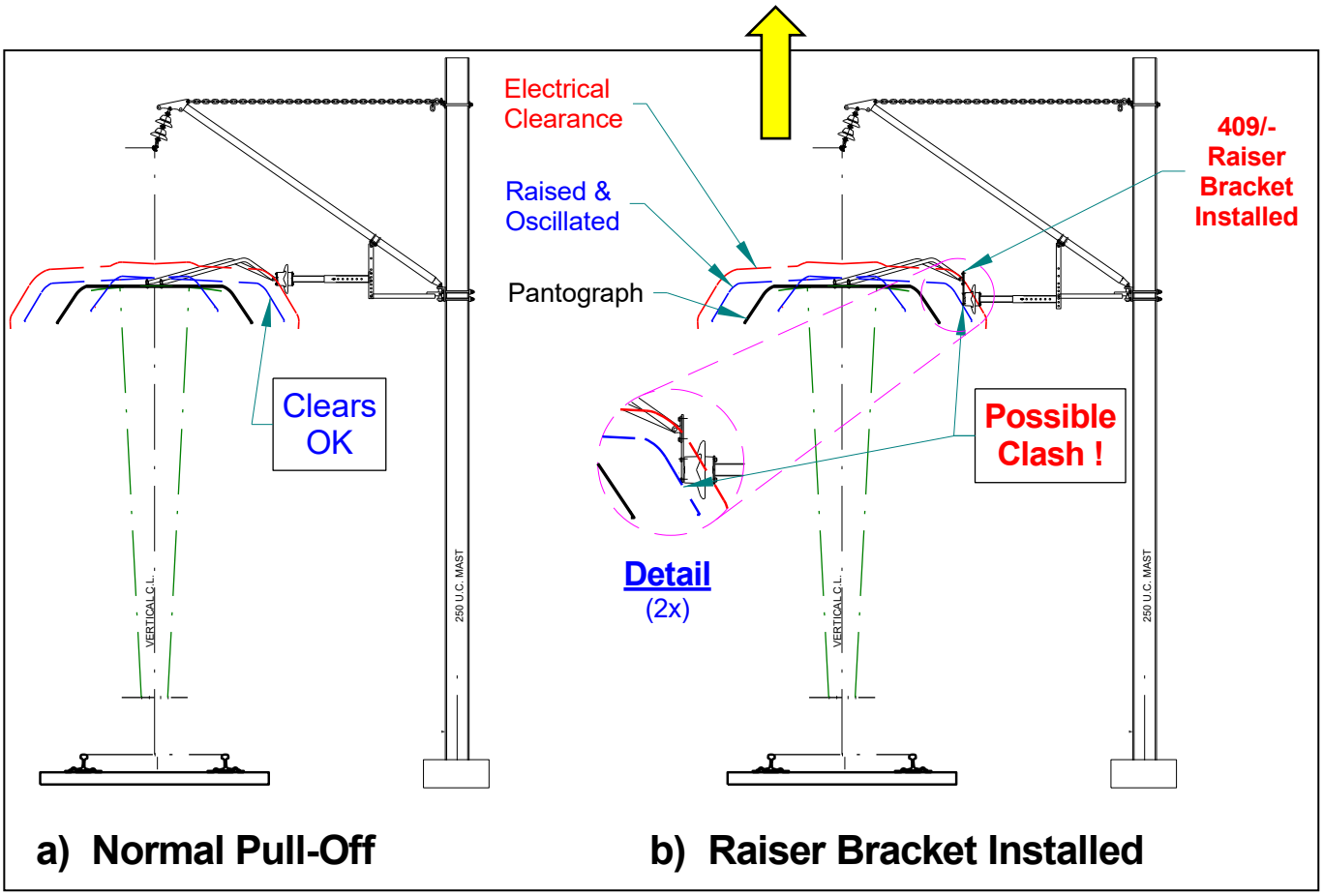


Figure 202 - Pull-Off Raiser Bracket "trap"

Figure 202 shows (a) the normal pull-off configuration on the left, and (b) this situation with the raiser bracket installed on the right.

In case (a) the raised & oscillated pantograph mechanically clears the heel of the arms, whereas in case (b) it can clash with the lower end of this steel bracket!

It demonstrates how easy it is to get into trouble simply by placing an object below the heel of the arms – in this case the bottom of the raiser bracket and attached insulator.

Note that, had the raiser bracket been installed the other way – placing the heel of the pull-off arms lower than the insulator – would not have caused any additional clearance concern here. Indeed, this is a common thing to see throughout the network, employed as a "quick fix" for obtaining suitable heel heights.

The situation in *Figure 202* is one of the many things that can cause "alarm bells to ring", and it's not easy to see the problem because the pantograph passes quickly by and no one is normally there to notice clearance issues. Also, the pantograph has to sway (oscillate sideways) quite a bit at this location for there to be a problem, but the clearance is required regardless, to cater for such excessive sways (e.g. partly caused by a sudden dip in one rail of the track).

It is one reason why it's important that design becomes involved to check out clearances if things don't seem to be working correctly in the field when building or adjusting the OHW. It's also the reason that the "PanGauge" spreadsheet was originally developed – it's a tool to quickly assess these tricky situations by entering a few numbers and seeing a graphical representation of the actual situation for a "go" or "no-go" assessment. That "picture" is worth at least a few hundred words(!). Refer to *The "PanGauge" Spreadsheet* in *Section 6.3.2.4* for more information.

The last thing to mention here is that these situations of uncertainty can also be a constant source of additional work, if others notice it too and become concerned and need to have them checked out as well. So, it's best to get it right the first time to avoid future questions.

PULL-OFF ARM ADJUSTMENT

Attempts had been made in the past to design some pull-off arms (or even knuckles) with a limited amount of adjustment on the arm itself.

Essentially this meant having the arm in 2 overlapping halves with multiple holes at a common spacing. Two bolts would then select holes to give the required arm length.

While this might seem a good idea, it does introduce a degree of unreliability should one of the bolts come loose over time (due to the significant and ongoing vibrations experienced by the arm as pantographs pass by).

This approach is no longer acceptable, and this is described further in *Section 5.1.21.3*.

3.2.0.6 Status (c. 2014)

N/A

3.2.0.7 Reference

Refer to *Table 20* and *Table 21* for specific types of support and registration arrangements.

3.2.1 Cantilever Arrangements

3.2.1.1 Description

A "cantilever" appears on the open route as a triangular-shaped frame, with horizontal chain at the top connected to a diagonal strut, and installed on a mast, portal leg or drop vertical.

It supports and registers the catenary wire using a pair of suspension insulators. The contact wire is registered (held in position) by additional components in this arrangement, typically including 1500V insulation and 1 or 2 pull-off arm/s. See *Figure 205*.

There are quite a number of different arrangements depending on their vintage and also their "Type" (which is based on the amount of contact radial load held at that location).

The population of cantilevers around Sydney's electrified network is huge, and growing, so it is vital that they be well designed, installed and maintained.

Note that "Tunnel Cantilevers" are dealt with further on under *Section 3.2.6, Tunnel Arrangements*.

3.2.1.2 Function

Cantilever arrangements provide a relatively simple, cheap and effective means of providing the following functions:

- They *position* both the catenary and contact wires at a particular height and horizontal stagger relative to the superelevated centreline of the track being serviced.
- They provide a means to *support* the resulting catenary weight (which also supports the weight of contact wire, droppers, in-span feeders, etc.), and to *register* the catenary and contact radial and wind loads, as shown in *Figure 205*.
- In the case of a regulated OHW system, they also allow the catenary and contact wires to *move longitudinally* as these wires lengthen (expand when hot) and shorten (contract when cold) relative to a fixed anchor or fixed mid-point location.

An additional functional requirement of the latest ("Mark-2") cantilevers is that they allow for "Independent Registration", i.e. there are no spans crossing between tracks. In this way any damage to the OHW in the vicinity of the cantilever should not affect the OHW for adjacent tracks.

3.2.1.3 Typical Components

Cantilevers achieve the above functions with arrangements that are relatively cheap to build and straightforward to maintain, using many common OHW parts.

They can be installed from vertical structures including masts, portal legs and drop verticals (suspended from a portal bridge or the like).

The main components include:

- Insulators (twin porcelain suspension insulators and/or post type insulators).
- Steel cantilever "Pipe" (or "Jib") in compression, to support the majority of the OHW weight load – see below.
- Chain length (with 50mm links), to take mechanical loads in tension – see below.
- "Tie rod" – see below.
- "Insulator & tie-rod end" fitting, a steel fitting which provides a junction for connecting the pipe and chain, and holds the catenary suspension insulators (in many cases with some lateral insulator position adjustment for changing catenary stagger) – see below.

- "Insulator post", which is a horizontal channel that projects out from a mast to support the post type insulator and pull-off arm/s – see below.
- Pull-off arm (or arms if twin contact) with swivel clamps to attach to and hold the contact wire/s in place.

CANTILEVER PIPE ("JIB")

The cantilever pipe (jib) is the diagonal steel member that takes the large downward compressive force resulting from the support of the adjacent half-bays of OHW conductors and other cantilever hardware (insulators and fittings). Refer to *Figure 185*.

The pipe diameter seems to be relatively uniform throughout the electrified network at 76mm outside diameter and 65mm bore, which is a common commercial size used throughout industry. This is about the minimum diameter and thickness needed to prevent the pipe from buckling under the compressive load (provided the pipe length is not too long).

Although the pipe is hot-dip galvanised, if there is any internal corrosion, it is difficult to detect (a potential hidden failure mode), until rust marks appear on the outside. Having said that, these pipes can last for 50 years or more, and the Liverpool to Glenlee cantilevers built in the 1960s are testament to this (although some are now showing significant corrosion and are being replaced). If installed near the coast, any atmospheric salt spray can accelerate internal corrosion, and this needs to be regularly checked.

CHAIN

The standard chain in OHW work is fitting 144/4, which is 13mm thick and has 50mm effective sequential spacing (initially it was 49.4mm as used in the CCalc program).

This chain has a specified minimum safe working load of 15kN, so it cannot normally be used to tension any OHW conductors (which are under much higher tensions). Refer to *Figure 185*.

This chain was primarily used on the dead side of the OHW, but in recent times it has also been used on the live side in limited applications, as a replacement for the copper span wire, but only in situations where there is little chance of any significant current feeding through the chain. So far so good.

When installed, it is highly desirable to orientate the chain without any twisting. This makes it far easier to count *pairs* of chain links when viewed from the ground, which is more reliable than trying to count individual links in a long length of chain. (Counting links is often done to confirm that a cantilever has the correct number of links, against the CCalc program output.)

When 2 links are connected together in tension, they are normally 90° to each other. However, at each point of connection, there is freedom to rotate their relative orientation by about ±20° from this position. In this way, if the chain arrangement needs to be progressively rotated through 90° to fit the orientation of specific end fittings, then this can be achieved with 5 or more links.
Said differently, you can have 1, 3, 5, 6, 7, 8, … links, or 2, 4, 6, 7, 8, … links. It takes 5 links to have the freedom to rotate an additional 90°.

TIE-ROD

A "tie-rod" is a 16mm diameter galvanised solid steel rod of a few standardised lengths, with both ends bent back into a "J" hook shape. This allowed for convenient attachment onto other hardware, including chain links. (Note that the top horizontal portion of the cantilever frame is often referred to as the "tie-rod & chain", with a few added links of chain for adjustability.) Refer to *Figure 185*.

The tie-rod came into existence many decades ago as a way of reducing costs (it was considered cheaper than using the alternative continuous length of chain).

These tie-rods are now no longer used, because of some failures over the years where the bent "J" ends had opened up under excessive loading or because they developed stress cracks (a manufacturing problem). Reliability was suffering.

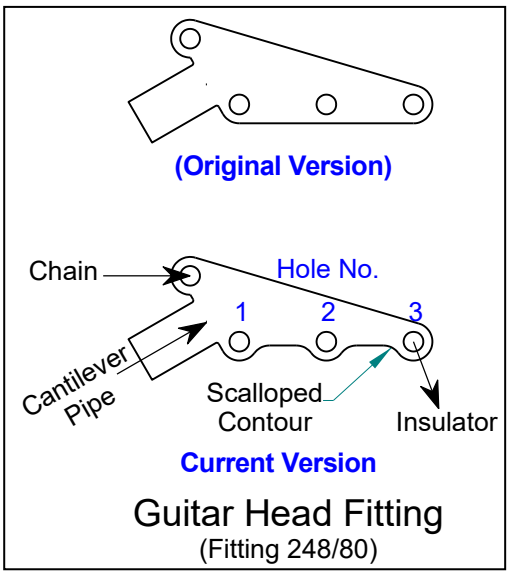
Instead the entire length is now made from chain (because the standard chain is now relatively inexpensive and more freely available). Shackles are provided at both ends, making it a more secure arrangement than if a tie-rod were used.

INSULATOR & TIE ROD END

There are currently 2 types of end fittings that join together the cantilever's horizontal tie-rod/chain and the diagonal cantilever pipe – colloquially known as the ***Guitar Head*** and the ***Mushroom Head*** fittings. They then provide a means of attaching the catenary suspension insulators.

"Guitar Head" Fitting

This fitting resembles the triangular shape of the head of an electric guitar. See image to the right, or refer back to *Figure 185*.



These fittings are suitable for low to medium insulator swing (from vertical). This normally (but not always) equates to Type 1 & Type 2 radial load situations. If the insulator swing is more than 45° from vertical (towards being horizontal), then the *Mushroom Head* fitting (below) should be used instead – for what this means see further back to *Figure 193*.

There are 3 holes spaced 115mm apart in a level configuration at 30° pipe angle. However, at other pipe angles the holes are not on the same level, and the small vertical offsets should be taken into account. The CCalc program works all the offsets out accurately based on the specific pipe angle.

These 3 holes are provided for some degree of convenient catenary stagger adjustment, should this be needed during its life. The 3 holes are numbered 1 to 3 working away from the support mast.

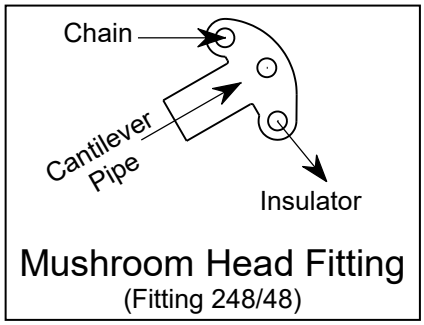
Ideally the centre hole (Hole 2) should be used when cantilevers are initially designed and installed, as it gives maintenance staff convenient ±115mm catenary stagger adjustment both ways in future (for instance, if the track is laterally adjusted). For the Gosford to Newcastle Electrification project in the 1980s, there was a policy of designing cantilevers using Hole 3 (the furthest hole), in anticipation of the main line track centres both widening from 3.66m to 4.0m in the future (then requiring Hole 2 or 1 to be used).

The lower portion of this fitting was eventually modified to be specially profiled (scalloped) in order to help maximise the insulator swing without causing the insulators to bind against the fitting. (Earlier fittings did not have these scallop cut-outs as shown in above diagram.)

Hole 3 is particularly suited to large insulator swings away from the cantilever (higher radial loads and/or low weight loads), and sometimes this hole is used for such situations. When in Holes 1 or 2, if the insulator swing is so great that it binds from further rotation, this causes

additional stresses on the insulators which, while they may still cope, should be avoided if this is practical to do so. See *Figure 193* further back for an idea of what this means.

"Mushroom Head" Fitting



This is similar to the guitar head fitting above, except there is only 1 hole (not 3) for installing the catenary suspension insulators. Refer back to *Figure 185*.

It is designed for high levels of insulator swing, due mostly to Type 3 radial loads. It cannot include the additional holes because the insulators would otherwise bind against the underside of the fitting (as mentioned above). The high insulator swings are mostly a consequence of high catenary radial loads, although sometimes small weight spans coupled with moderate radial loads can also generate similarly high insulator swings. (For instance, this might happen in the bays approaching a low overline bridge, where catenary heights are successively reduced, possibly causing low weight spans.)

There is another hole – in the middle. I'm not sure of the reason for this, but it may have been provided as a rigging attachment point for Type 3A cross-track spans (although not sure if this is always appropriate).

INSULATOR POST

An "insulator post" is often employed to support and locate a post type insulator out from the mast, portal leg or drop vertical structure. The other side of the insulator holds a pull-off arm so that a suitable contact stagger and heel height can be set. See *Figure 203*.

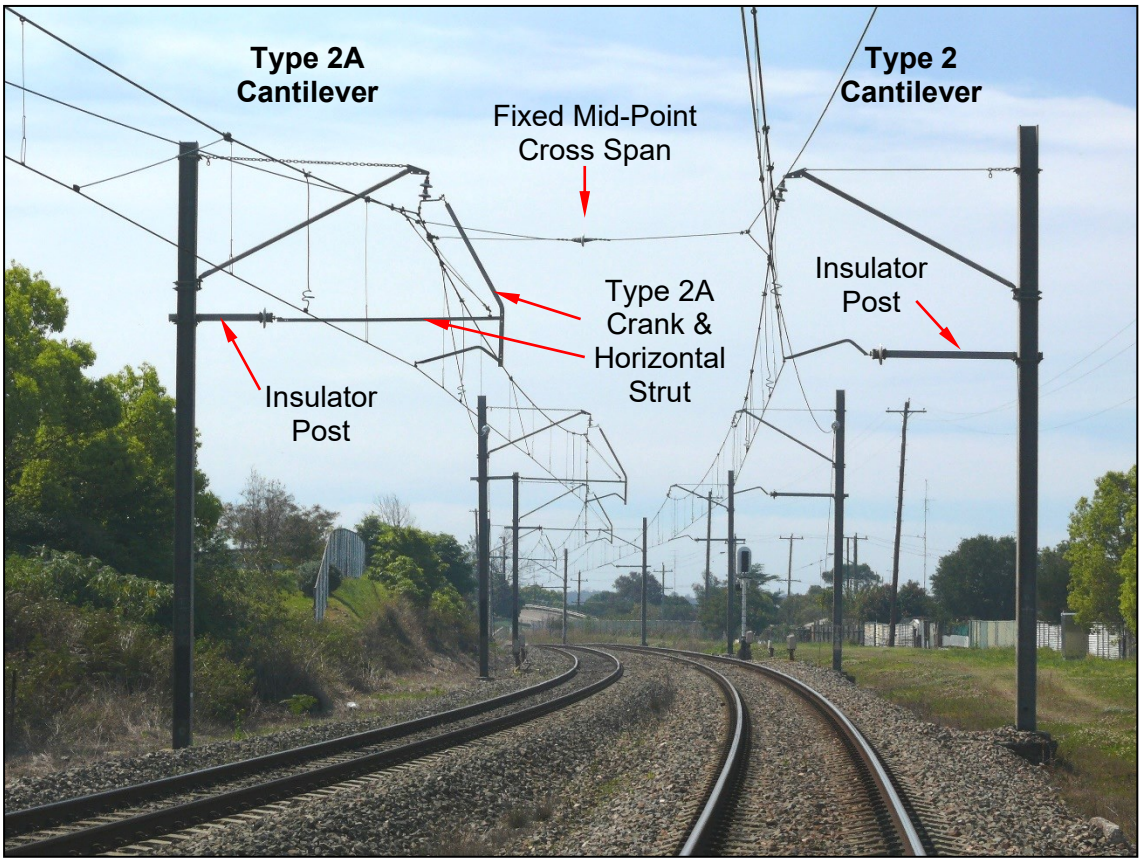


Figure 203 - Insulator Post on Mk-1 Cantilevers (Gosford to Newcastle)

The insulator post (fitting 189/-) is normally a horizontal steel channel section, which is attached to one side of the support structure using a mast attachment bracket (fitting 188/-)

including a pair of special deep "U-bolt" fittings. These U-bolts allow some horizontal adjustment of the post for getting the correct contact stagger. The mast attachment bracket can be adjusted up and down to get the correct heel height. The standard lengths of the main insulator posts come in 300mm increments, e.g. 1.5m, 1.8m, etc.

Sometimes a "cranked" arrangement is needed in order to clear certain obstructions located at the mast near the contact height level where the post would normally be attached, e.g. a cantilever's jib support bracket or a portal knee-brace. See *Figure 204* for instance.

Various vertical offsets are available, with 150mm or 300mm being typical. Most cranked arrangements use a diagonal channel portion, whereas some just use vertical and horizontal members to provide the offset, as shown between tracks in *Figure 176*.

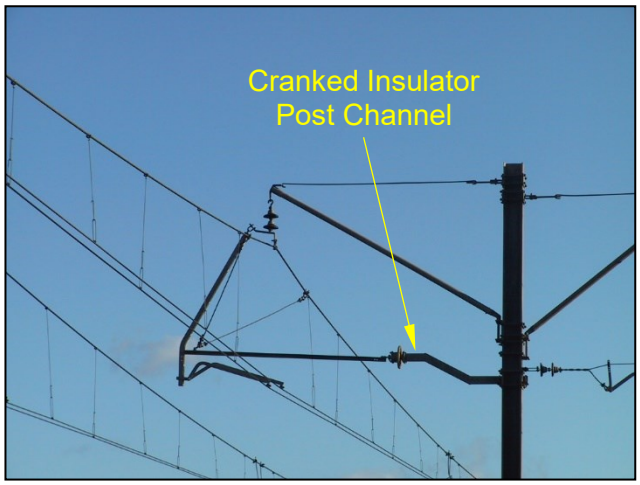


Figure 204 - Cranked Insulator Post Channel

Using the cranked insulator post with high radial loads can place enormous bending moments on the mast attachment bracket, which may be unsuitable in some instances.

In addition to registering the contact wire, sometimes the insulator post arrangement is used to register the catenary as well. This happens in some standard pull-off arrangements, and the key requirement in that case is to align the 2 post type insulators (for catenary and contact) vertically in-line for reasons of safety.

TYPE 2A CRANK ARRANGEMENT

Of special note is the Type 2A arrangement. Here, a horizontal strut (made from steel angle) is attached beyond the post type insulator on the live side. This strut takes the contact wire negative radial load from the pull-off arm through the lower part of the diagonal crank fitting, and its compressive force is transferred back to the support mast.

Both *Figure 203* and *Figure 204* show a Mark-1, Type 2A cantilever. (This is no longer used for new works, because of its awkward and sometimes unstable nature – refer to *Section 3.2.1.5*, *Type 2A Problems*. Replaced by the Mk-2 version from c.1984.)

This configuration allows the pull-off arm to be located on the *remote* side of the track. For *low to medium contact radial loads* (acting towards the mast), this places the arm in tension, which helps with the dynamics of the registered contact wire interacting with the trains' pantographs. It's mostly done because it is cheaper than providing alternative arrangements, such as installing a portal and drop vertical to reach the same location where the pull-off arm needs to be. However, it is unsuitable for high negative contact radial loads (Type 3).

The "crank" is a diagonal strut that is connected near the catenary at the top, attaches to the horizontal strut lower down, and connects the pull-off arm at the bottom vertical portion. This short vertical bottom end provides a limited amount of heel height adjustment.

There are 2 steady wires connected from the horizontal strut, up to the catenary wire on both sides of the cantilever, forming a "V" shape, so as to stabilise the position of the crank.

The crank is designed to collect the contact as well as a good portion of the catenary radial load, and transfer these loads back to the above horizontal strut. Note that the weight of the both adjacent half-bays of OHW conductors, supported at the catenary insulator string, helps keep these catenary insulators close to vertical.

The current Type 1A and 2A cantilevers (the Mk-2 series) do not use such a steel crank, but instead they rely on a horizontal I-beam (called the "horizontal boom") to take only the contact radial load back to the cantilever pipe and mast. See *Figure 206* further on.

The catenary radial load is handled by the swung catenary insulator string. But the amount of catenary insulator swing in this case is lessened, because this horizontal boom is supported by 2 wires, each at a 45° incline taking on a "V" shape up to attach to the catenary wire – see Detail "A" in *Figure 206*. The considerable weight of the horizontal boom, arms and post type insulator, plus the bending moment caused by the contact negative radial load attached about 400mm lower down, all transfers up to the catenary via the support wires. This extra weight to the catenary helps to make these insulators more vertical. This is a good outcome of this arrangement, because it lessens the chance of the insulator string jamming on the guitar head fitting or pipe (especially if hole number 1 is used). CCalc works out all the details.

3.2.1.4 Configuration

The fundamental cantilever portion (which positions and supports the catenary wire) is made in the shape of a triangle with the 3 sides as follows:

- A top horizontal length of *chain* (this is always meant to be horizontal and in tension),
- A length of 76mm diameter steel *pipe* (inclined around 30° to horizon), called the "pipe" or "cantilever jib" (which is always meant to be in compression), and
- The vertical *support structure* (steel mast, portal leg, drop vertical or wood pole).

Refer to *Figure 205*, which shows the horizontal chain, inclined pipe and associated fittings in **blue**.

The end of the top horizontal chain has a fitting which accepts the suspension insulators, that in turn holds the catenary wire (which then supports a portion of the conductor hardware in both adjacent bays).

In this configuration the support structure (mast, etc.) needs to be at least 500mm higher than the catenary height, as this accommodates the length of catenary suspension insulator string when vertical (about 450mm). Mast heights are typically standardised at 1,000mm higher than standard catenary height for any specific project, to provide some degree of adjustment later on if needed.

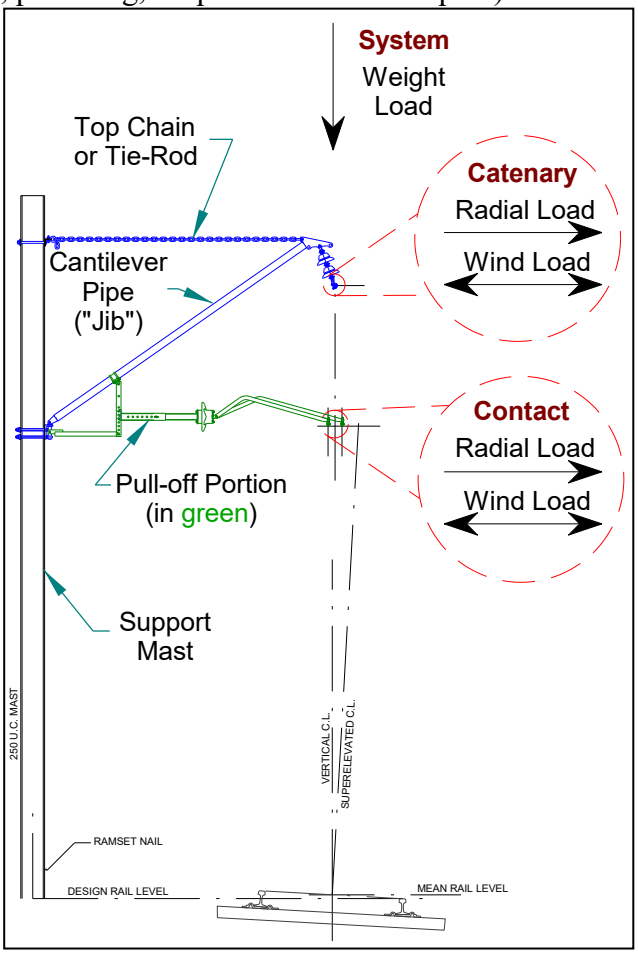


Figure 205 - Cantilever & OHW loads

The cantilever frame provides an effective support arrangement, since the vertical height difference between the top and bottom of the inclined jib (pipe) makes good use of the necessary catenary to contact vertical distance (*system depth*). This is typically 1.5m (or about 2m for older regulated systems) and it is necessary for accommodating the deepest catenary sag in the longest bays (of 67m or so).

The lower part of the cantilever arrangement deals with registering the contact wire/s, as shown in **green** in the above diagram. This pull-off configuration depends on the specific

cantilever *Type* – Type 1 or Type 2 is shown in the diagram (with heel height being the only physical difference between the two). This area includes the pull-off arm which registers the contact wire position, and in doing so handles the resulting contact wire radial and wind loads.

Note: This lower part may be omitted if the blowout resulting from the longer unattached contact span is deemed acceptable and does not jeopardise pantograph security.

The specific details of the triangular cantilever frame are calculated by the CCALC computer program for the Mk-2 cantilevers (and the "MAST" program for Mk-1 cantilevers). The cantilever is constructed knowing the *pipe length* and *chain length*, and also the *heights to the underside* of the 2 associated attachment brackets:

- The "tie-rod bracket" (top bracket on mast) and
- The "jib support bracket" (the next bracket down, located at the bottom of the pipe).

Aside:

When locating brackets on a mast, etc., it was decided to mark a horizontal line on the structure using permanent marker, at the height from reference nail as output by CCalc (or other program). The relevant bracket could then be installed with its lower edge – the *underside* of the bracket – aligned with this mark.

In this way, it's possible to check at a glance whether the bracket was installed to the mark, or whether some adjustment was made (and by how much), which can help enormously if troubleshooting is needed later. (That is, provided the measurement was made accurately in the first place.)

Many of the cantilever arrangements only require the 2 attachment brackets to the mast, but some also require a third bracket below the other two, for supporting an independent pull-off arrangement. In these cases, the height to the underside of the "pull-off bracket" is also produced so the complete arrangement can be made in the field.

Table 23 lists the various standard cantilever arrangements that have been developed and used in the electrified system since about the 1960s.

Description of Cantilevers	Reference
Liverpool - Glenlee Cantilevers	C/77487 sh.1 to 3, B/77614
Mark-1 Cantilevers ** (e.g. Gosford to Newcastle, Loftus to Waterfall)	Example: C/82387 sh.1 to 3 B/82513 sh.1 to 3 K/82390 sh.1 to 3
Mark-1 Variant - Cantilevers on Wood Pole	C/80276
Mark-2 Cantilevers (e.g. Waterfall to Port Kembla, recent OHW Upgrading Program & current standard cantilevers)	Examples: B/85084 sh.1 to 11 EL0194773-783 (twin contact) EL0003384-394 (twin / twin) EL0006173-183 (single contact)

** – Mk-1, Type 2A Cantilever is not to be used for future work.

Table 23 - Standard Cantilever arrangements

CANTILEVER TYPES

For the past 40 years or so, the cantilevers have been broadly categorised as Type1, Type 2 or Type 3, based on the *amount of contact wire radial load* at that location.

The *direction* of that radial load then determined whether to use the *normal* arrangement or an *Alternate* one, adding the suffix "A", e.g. Type 2A. Note that +ve radial load is acting away from the support structure, -ve radial load acts towards the structure.

Figure 206 shows 2 typical current Mk-2 cantilever arrangements with a configuration suited to straight track or large radius curves, i.e. situations that have a low to medium contact radial loads. They are Type 1 (or Type 2) on the left, and Type 1A (or Type 2A) on the right.

Types 1 & 2

The cantilever on the left has the contact wire radial load acting in a direction away from the support mast towards its track – a "positive" radial load. Its configuration is referred to as either Type 1 or Type 2, depending whether the radial load is small or medium (about 600N and 1,200N respectively for single contact).

The amount of *heel height* is the only significant difference between the 2 arrangements, viz. 100mm for Type 1, and reduced to 50mm for Type 2. (The higher heel height is intended for improved contact wire "compliance" under low radial loads.)

Types 1A & 2A

The cantilever on the right has the radial loading acting in a direction from its track back towards the support mast – a "negative" radial load. It is referred to as either Type 1A or Type 2A, again depending on the size of the contact radial load (about -600N and -1,200N respectively for single contact). As mentioned above, the "A" in the cantilever type means "Alternate", because this special configuration is needed to handle the negative radial loads (keeping the pull-off arm in tension), for stable high-speed pantograph operation.

Again, the amount of *heel height* is the only significant difference between these 2 arrangements, with the same 100mm for Type 1A and 50mm for Type 2A.

Here, the pull-off arm/s are attached via a vertical pull-off arm attachment to a "horizontal boom" which includes the contact post type insulator. The pull-off attachment bracket is adjustable horizontally along the boom to position the arms for the correct contact stagger. This boom takes the compressive radial load eventually back to the mast. It needs to also cope with a certain amount of bending moment applied to it, due to the depth of the vertical pull-off arm attachment (about 400mm) and the radial load in these arms. This bending tends to make the boom bow very slightly upwards in the middle (near the insulator).

The weight of the boom (including the bending moment applied to it), is supported by 2 wires in a "V" shape, which are each attached to the catenary either side of the suspension insulators. These wires should ideally be installed at 45° to the vertical for stability – see *Figure 206, Detail "A"*. The length of these 2 wires is also set so that the boom becomes horizontal, again for reasons of stability.

In both of the above cases – Type 1 / 2 and Type 1A / 2A – the radial loads are in the direction to the right. This situation is typical when both tracks (Down & Up) are on a right-hand track curve. (Obviously it's the mirror image when tracks are on a left-hand curve.)

Also, these arrangements need to provide a "solid" registration, in case an opposing wind load comes close to or overcomes the radial load – the heel of the arm/s must not droop down into the path of a train's pantographs. Refer to *Section 5.1.23.8*, *Adverse Condition* for further details on this.

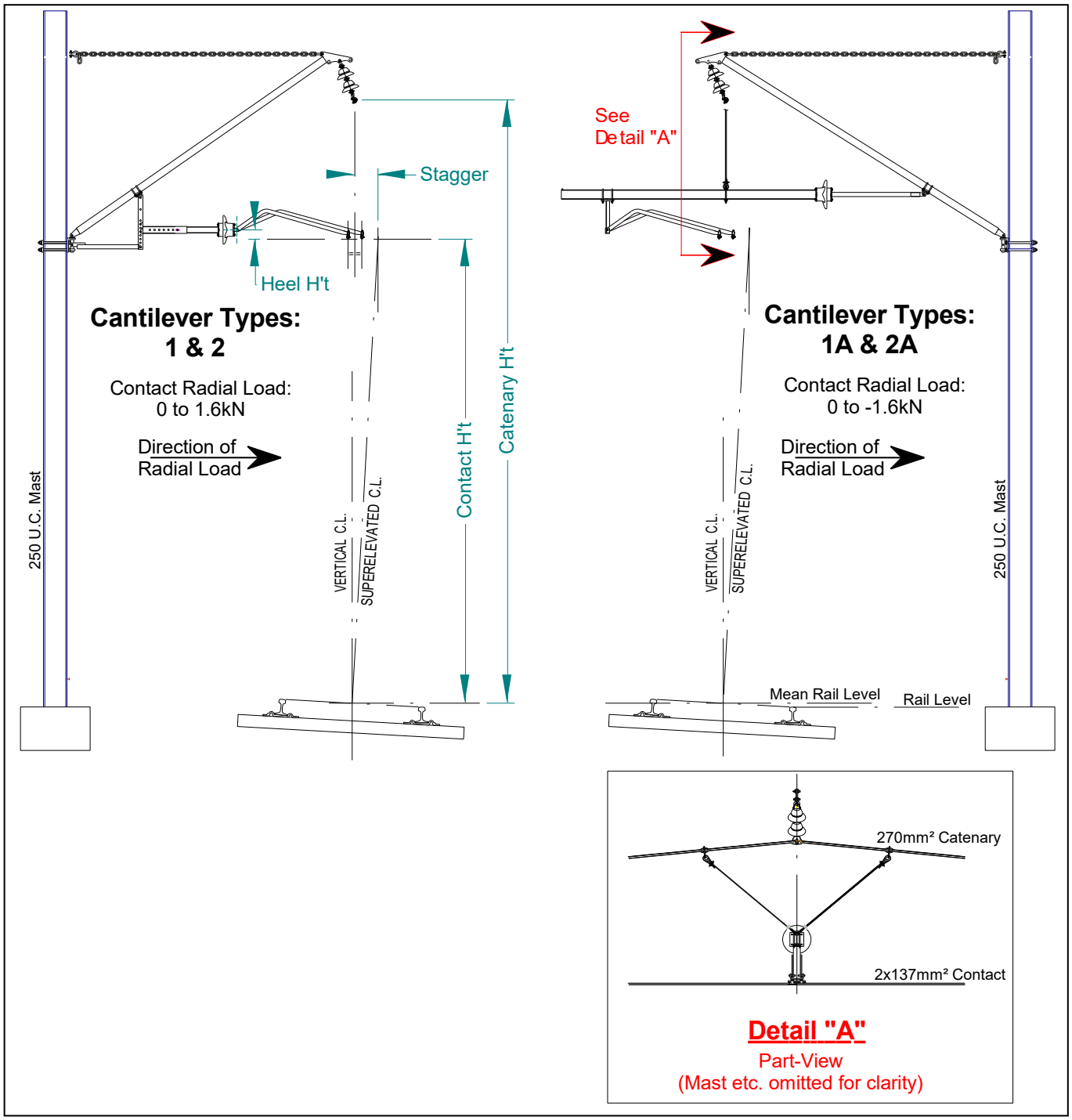


Figure 206 - Typical Type 1 & 1A Cantilevers (Mark-2 series) on Masts

Type 3

A *Type 3* cantilever is designed to handle *high positive radial loads* (those greater than Type 2). These occur when registering wire on tight track curves, and at turnouts where the direction of the catenary and contact wires often changes abruptly at the S&R location. (It's the amount of wire deviation from straight line that determines the radial load at that point, with a larger deviation generating a larger radial load.)

Refer to *Figure 207* which shows the current Type 3 cantilever installed on a portal leg (on the left), and a Type 3 cantilever installed on a Drop Vertical located between tracks (to the right). This second arrangement has a slightly different contact pull-off arrangement requiring a 3rd attachment bracket to the structure (DV).

The fundamental requirement for using this arrangement is that the high positive radial load should always be much greater than any opposing wind load on the contact wires (satisfying the "Adverse Condition"), so there's no chance of the heel of the arm/s drooping into the path of a pantograph. As a result, the pull-off arrangement for Type 3 cantilevers can be made much simpler and cheaper by using *span wires* or *chain links* (providing ready adjustability) instead of the solid arrangement of Types 1 & 2, and there may be other advantages as well.

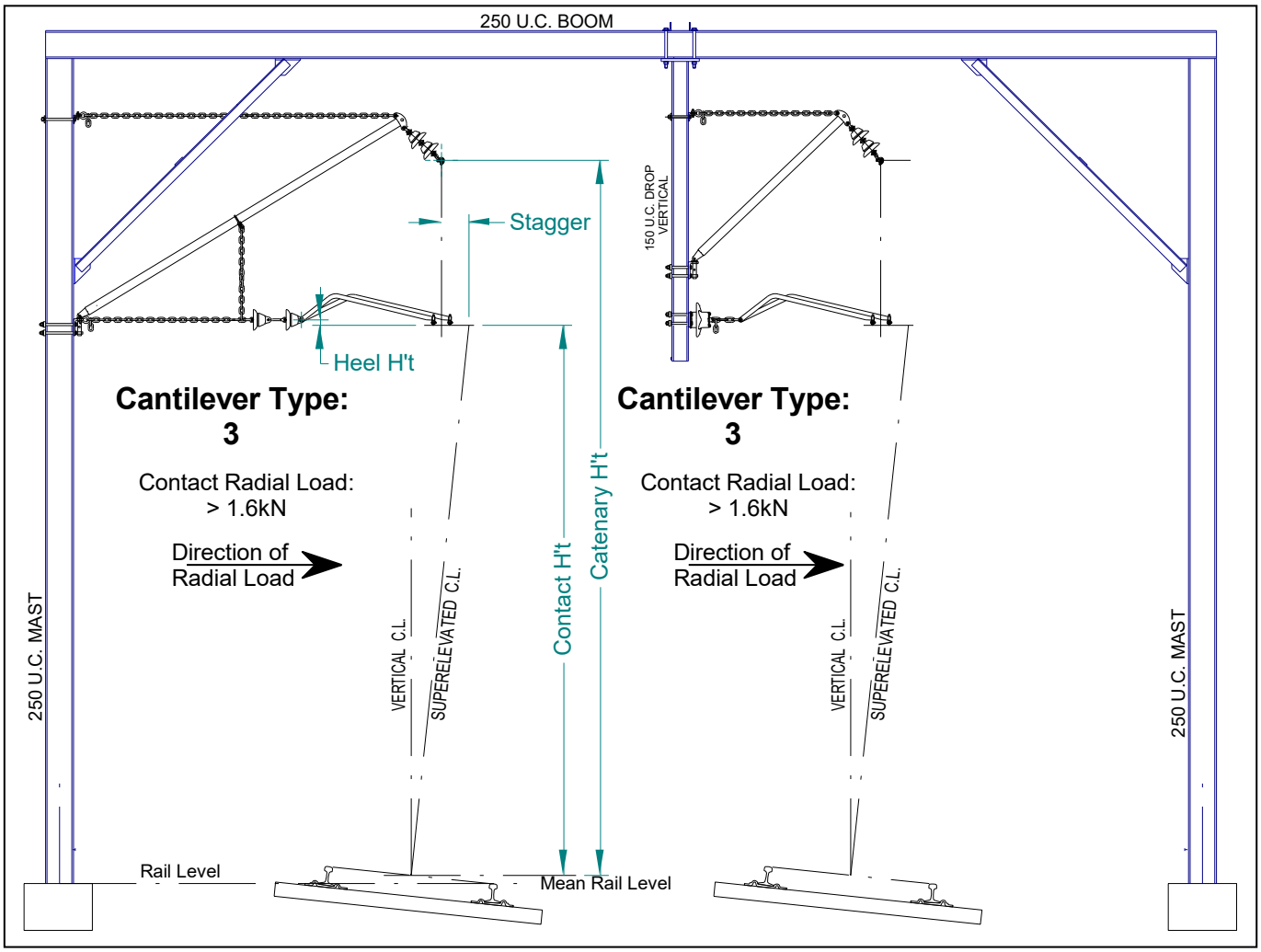


Figure 207 – Type 3 Cantilevers on Portal Leg & Drop Vertical

Figure 208 shows a situation with 5 cantilevers installed on a portal structure (and a set of tension regulator weights installed on the left portal leg at front and right leg at rear).

In this situation, all radial loads are acting towards the left. The left-most 3 cantilevers are Type 3 (with span/chain to arms), and the others are Type 2 (solid pull-off arrangements).

The actual form of a cantilever used in any situation depends on a number of factors, such as:

- Size and direction of radial loads. This dictates the cantilever Type *number*.
- Available *system depth* (catenary to contact distance). This can dictate whether the cantilever is installed on a mast or if it needs to be from a drop vertical.
- Horizontal distance from support structure to track (or more precisely, to end of pull-off arm). Again, a cantilever on mast or portal leg can cope with larger distances (2.5m to 3.9m to vertical centreline of track), but shorter distances (less than about 2.5m, this time referenced to the superelevated centre of track at contact wire height) may require a drop vertical instead (suitable down to about 1.7m).

- Amount of longitudinal catenary and contact wire movement with temperature extremes. For short distances (up to 100m) from a fixed anchor or fixed mid-point, a simple "Suspension" arrangement from a portal bridge can be used instead of the normal cantilever frame – refer to *Section 3.2.2, Suspension Arrangements* for more. This alternative can save on the amount of equipment and cost; however, it does require a portal structure (not a mast which is cheaper) – but there can be several Suspensions from the same multi-track portal bridge, potentially saving costs.

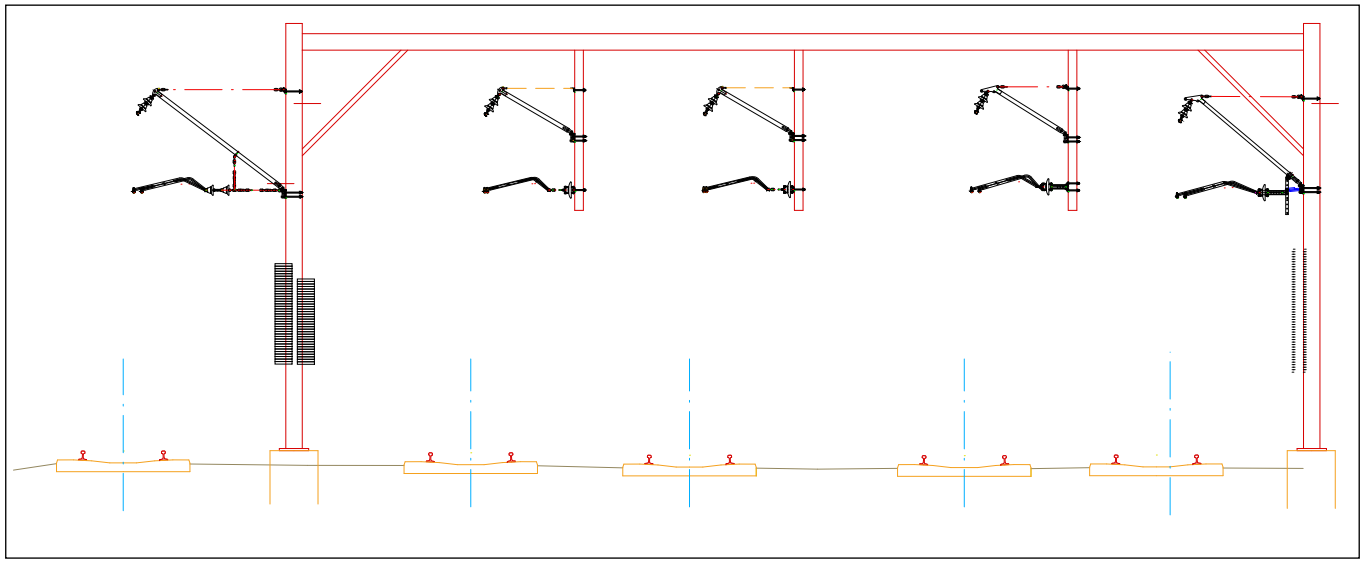


Figure 208 - Cantilevers on a multi-track Portal structure

So, cantilever arrangements are fundamentally categorised according to the *radial load of the contact wire*. Contact wire compliance is extremely important for providing a smooth arcless pantograph interface, and the contact wire's radial load has a big effect on compliance – so too does the heel height on the pull-off arm, described in *Section 3.2.0.5, Compliance*.

There are different ways of registering the contact wire depending on its radial load, and there are consequently 3 ranges of radial loads corresponding to the 3 "Types" of cantilever constructions. Refer to *Table 24* which show the contact radial load zones for Type 1, Type 2 & Type 3 cantilevers, for three quite different regulated OHW systems with differing regulated conductor tensions.

The contact radial load is a function of the contact wire tension, so the threshold radial load between the various Types of cantilevers may vary between OHW systems, per *Table 24*.

		Radial Load Zones for Cantilevers		
OHW System	**Contact Tension**	**Type 1**	**Type 2**	**Type 3**
Gosford to Newcastle Single Catenary / Single Contact	16.5kN	0 to 550N	550 to 1,000N	More than 1,000N
Current Standard OHW System Single Catenary / Single Contact	18.0kN	0 to 500N	500 to 1,000N	More than 1,000N
Current Standard OHW System Twin Catenary / Twin Contact	12.5kN each (= 25kN)	0 to 800N (total)	800 to 1,600N (total)	More than 1,600N (total)

Note: 10kN Tension ≈ 1 tonne mass

Table 24 - Radial Loads for typical Cantilever "Types"

CANTILEVER USE IN FIXED-ANCHORED OHW

The above radial load zones are applicable to regulated OHW, but it's a bit more complicated for fixed-anchored OHW where the tension (and so the radial load) changes with temperature.

While these cantilever arrangements can be used to support and register OHW in fixed-anchored systems, determining the relevant cantilever Type (1, 2 or 3) is less straightforward.

Thus, during the design stage, great care should be exercised when using cantilevers in any fixed-anchored OHW system.

Primarily, this means checking that the *Adverse Condition* in each instance is OK for the cantilever Type selected, so that there is no chance that the pull-off arm can slump into the path of a pantograph. For this, different temperatures (hot & cold) and associated wind speeds need to be checked out. See *Section 5.1.23.8*, *Adverse Condition*.

Also, the Type 2A cantilever in particular can't handle excessive negative radial load.

3.2.1.5 Design Notes

CANTILEVER REQUIREMENTS

As with other Support & Registration equipment, the cantilever arrangement locates the catenary and contact wire/s in the required spatial position, i.e. the height and stagger of these wires relative to the design superelevated track position.

It also supports the vertical weight of the OHW conductor hardware and registers the horizontal radial and wind loads of both catenary and contact wires.

Cantilevers achieve these requirements with minimal equipment, making them a relatively efficient support device. There are significant cost savings with 2 simple masts in the ground with cantilevers installed on them, compared to the alternative portal structure with associated bridge spanning 2 tracks (or more). Even more efficient are back-to-back cantilevers installed on a single mast located between 2 tracks (if the distance between track centres permits this).

There have been 3 main versions of open-route cantilevers over the years dating back to the 1960s, as listed in *Table 23* and as detailed further below:

- The original ***Liverpool to Glenlee*** cantilevers, then
- The ***Mark-1*** cantilevers, and then
- The current ***Mark-2*** cantilevers.

Fixed-Anchored Issues

I may be wrong, but I think Sydney's cantilevers were originally developed to support regulated OHW conductors (to allow the wire to moving longitudinally with temperature), although they have also subsequently been used in fixed-anchored OHW over the years because they are relatively easy to install (among other things).

However, extra care needs to be taken with applications in fixed-anchored OHW, especially since conductor tensions change to being tight or slack (cold or hot temperatures). This in turn affects the *radial loads* on catenary & contact wires at the S&R location. So, the following aspects typically need to be checked out during the design:

- Altered catenary suspension *insulator swing* – the change in horizontal and vertical swing components with temperature, can each lead to reduced catenary clearances to nearby objects. See *Figure 193* further back.
  Through the droppers, this can also raise or lower the supported contact wire, which may become crucial when the contact height is already low, e.g. approaching an overline bridge. The contact height needs to always remain > 4.57m above track.

- It can also be a problem in high radial load (Type 3) scenarios, if a pull-off chain or span wire holding the arm/s becomes slack as the contact radial load diminishes. The *Adverse Condition* should be checked out in this case – see *Section 5.1.23.8, Adverse Condition*.

MINI-CANTILEVERS

When they were first devised for Sydney, cantilevers installed on *drop verticals* (rather than masts or portal legs) were referred to as "Mini-Cantilevers" for obvious reasons.

The configuration on drop verticals is slightly different – mostly in the pull-off arrangement (since the structure is closer to the track – some 2m instead of 3m away).

Sadly, the term mini-cantilever has not really taken off, possibly because the difference between the cantilever sizes is not that important, nor is their difference in configuration.

So, they tend to be simply referred to as *cantilevers on drop verticals*.

LOCATION OF DROP VERTICALS TO TRACK

Refer to *Section 3.3.3.4, Drop Verticals* for more details on the standard approach to locating drop verticals laterally relative to track.

When locating each drop vertical on a portal (or other structure), its lateral position is normally set so that its closest face is a certain distance from the design *superelevated* centreline of registered track, at contact wire height. See *Figure 209*. The term "Face of DV to Design Track Super C.L." is most often used, and this horizontal distance is usually about 2.1m (but can range anywhere from about 1.7m to 2.5m or so, depending on the specific situation).

The reference to design *superelevated* track (rather than *vertical* track position), was adopted so that the OHW designer could specify a standard offset, say 2.1m, for most drop verticals, *regardless of the amount of track superelevation*. (The recommended standard distance is given on the appropriate cantilever standard arrangement drawing.)

Importantly, this meant that the available space provided by this offset could readily accommodate the insulator/s, pull-off arms, etc., that were needed in the cantilever's pull-off arrangement. This is irrespective of the specific track superelevation.

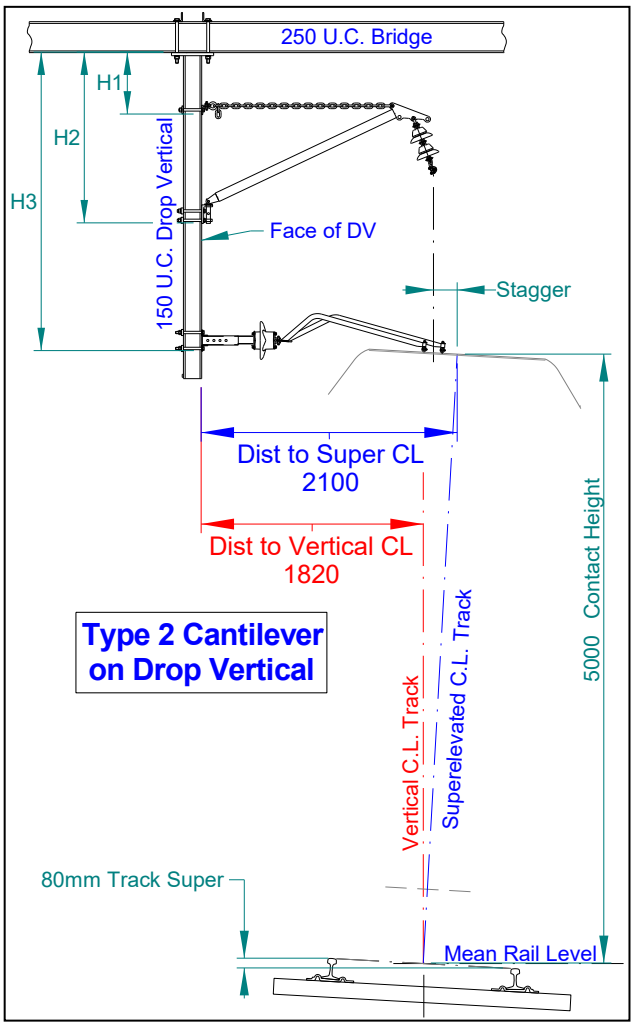


Figure 209 - DV position relative to track

In this way, from location to location, the pull-off arms were likely to be all the same lengths (provided the stagger didn't change), and this proved to be quite beneficial for a few reasons.

This approach meant that it didn't matter if the track was straight, or on a curve, or in a transition to a curve (with each case having different values of superelevation). It really meant that no calculations were needed at the early stage of design to confirm arm lengths (that is, unless the offset space was much less than 2m).

But there is a slight down side to this approach – later on in the design process, the drop vertical positions need to be related to the *vertical* centreline of track for convenience of installation by Civil Construction staff, using the "Drop Vertical Length & Position Tables" spreadsheet which the OHW designer hands over to Civil Design (see *Figure 320*).

When locating the various attachment brackets on the drop vertical, instead of measuring vertically up from the nail (which could be quite a distance away laterally), the measurement was taken from the underside of the portal bridge down to the underside of the brackets. Refer to heights "H1", "H2" and "H3" in *Figure 209*. CCalc assumes a horizontal bridge.

For more information on aspects of drop verticals see *Section 3.3.3.4, Drop Verticals*.

EXTENT OF LIVE EQUIPMENT

For many decades there has been a policy of using "dead" cantilevers wherever it's practical.

"Dead" & "Live" Cantilevers

Referring to *Figure 210*, a "Dead Cantilever" (for want of a better term) is one where the bulk of the cantilever (particularly the triangular support frame) is at, or near, earth potential. *This is achieved by placing insulators as close as practical to the live catenary and contact wires*.

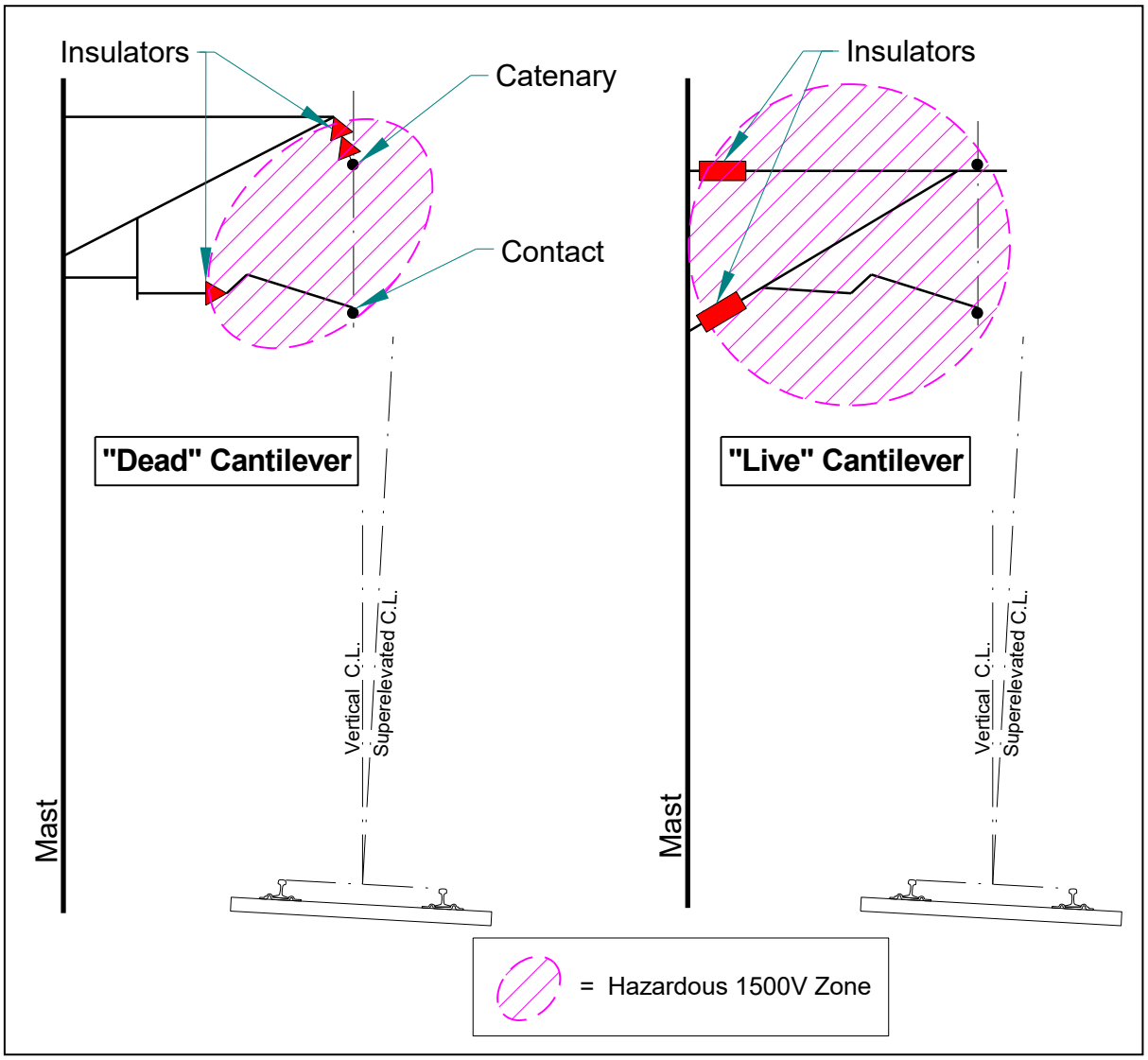


Figure 210 - Comparison of "Dead" & "Live" Cantilevers

In all of Sydney's open-route cantilever arrangements (of the various vintages), the catenary insulation is right next to the catenary. This makes the bulk of the steel frame of the cantilever unenergized and thus close to earth potential (i.e. typically attached to a mast installed in a concrete foundation in earth – some are even rail-connected via spark gap).

Likewise, the insulator for the contact wire registration is usually located at the end of the pull-off arm that's remote from the track, again leaving the rest of the steel registration arrangement back to the mast at close to earth potential. This is similar to the various portal "Suspension" arrangements, which also have the bare minimum equipment energized at 1500V.

On the other hand, a "Live Cantilever" is one where the insulators are located next to the support mast, resulting in a greater amount of exposed (live) equipment, including the cantilever frame itself. It seems that most cantilevers in other OHW networks are usually live cantilevers, notably those of the 25kV ac systems.

Figure 210 shows that the amount of exposed live equipment (shaded in pink) is much greater in the case of a live cantilever, and this aspect may lead to problems in a heavy current dc OHW system, as described next.

Past Policy

In Sydney's electrified network, there's been a policy or practice in place for many decades (and maybe even back to the early days of electrification), of *minimising the exposure to "live" 1500V equipment* wherever this can be practically achieved.

I guess this is much like the "prudent avoidance" approach adopted by the NSW electricity industry when faced with the uncertain "emf" health issues in the 1990s. (*If people don't need to be exposed to a possible hazard, then as a first step, make arrangements that keep people well clear of that hazard, if the costs to do so aren't unreasonable*.)

I mention this because many of the designs of the various support & registration arrangements have adopted this policy of keeping much of the steel equipment "dead" (unenergized), in an effort to minimise the extent of the *exposed* 1500V hazard.

Reasons

I think the policy of designing *dead* cantilevers was basically for reasons of safety, as it reduces the amount of *exposure* to equipment that's live at 1500V in the system.

Although less likely, I'm guessing that it might also have been that "solid" 1500V insulators to suit live cantilevers were not available in a slender configuration and of a suitable strength, whereas today the insulator options are far greater. Unfortunately, the conductor sizes used in Sydney are necessarily large and therefore heavy by comparison with other electrified rail systems, and the tensions and thus mechanical loadings are likewise much greater – so the insulators would need to be incredibly strong.

The problem with a relatively low voltage of 1500V dc is that, to get the required power to the trains, the current must of course be high (viz. Power = Volts × Amps).

But when the system current is high, it becomes more difficult to discriminate between the train's heavy (but normal) accelerating load current (good), and an electrical fault on the system (bad). The dc circuit breakers are set to values of up to around 6,000 amps, which is a huge amount of current, and this is quite capable of causing enormous damage to equipment etc. if the fault current isn't quickly detected and isolated (i.e. in much less than a second). Note that the dc circuit breakers can also trip on "rate-of-rise" of this fault current and predict a fault, but it may not always be sufficient to reliably trip supply because it depends on the nature of the fault. Refer to *Section 5.7.2*, *The Nature of the dc Supply to OHW* for more details.

It's obvious that the greater the *exposure* of live equipment to the surroundings, the greater is the *risk* of something happening which results in an electrical fault or some other problem.

Having said that, it's likely that Sydney's *dead* cantilever policy was (at least in part) put in place due to *the difficulty of reliably detecting, discerning and clearing a true fault* in this dc system *in all situations*.

The additional amount of equipment that's at 1500V in a *live cantilever* makes the exposure, and therefore the risk of fault occurring from "outside" interference, that much greater.

In other words, if there is no operational or other need for the cantilever to be *live*, then why increase the risk of a fault by having it *live*?

While this may seem trivial, installing *dead* cantilevers, wherever this is practical, is at least something that can be done (at virtually no cost) to reduce the above exposure and consequent risk. And bearing in mind the huge population of cantilevers throughout the electrified network (in the multiple thousands), this policy should yield a lower overall risk and better ongoing outcome into the future.

*A **hypothetical situation** may help.*

If some nearby *metallic object* was to fall onto the *top horizontal chain* of the cantilever triangle without causing it to fail, and this was a *live* cantilever, it would liven up the object itself to +1500V dc.

If that object was somehow electrically connected to the traction negative return path, then in this situation there's a good chance that the DCCBs will trip on *overcurrent* or *rate-of-rise* protection, thus rendering the situation safer.

However, if the livened object is simply touching the earth at one or more points, or is just left electrically "floating", then there would likely be little or no fault current and the protection cannot be expected to operate. In this case, the object would probably stay alive until noticed by someone. (Note that all masts for holding S&R equipment used to be spark-gapped to rail, and this would have helped in this particular scenario, but because of copper theft, a lot less structures are spark-gapped these days – see *Section 3.12.0.5, Removal of Bonding* for more on this.)

Indeed, depending on the length of the fallen object or other connected objects, it may transfer the electrical hazard elsewhere. And you can't rely on the electrical protection to trip because the DCCB trip level is set so high that it may not "see" the fault to isolate it. So, this is an increased hazardous risk.

On the other hand, having a *dead* cantilever in this same scenario greatly reduces the risk of that same object livening up to 1500V in the first place – the object rests on the cantilever (provided the chain is strong enough).

With so many new buildings and structures being built close to the rail corridor these days, the chances of the above example happening are likely to increase. Having dead cantilevers minimises that risk.

Indeed, on extremely windy days there are often reports of materials of all sorts being blown onto the OHW, including sheets of corrugated iron, metal cladding materials, scaffolding from high rise development, etc. This situation cannot readily be controlled, so again, the less extent (exposure) of live equipment out there, the better.

As a consequence, in the past this *dead cantilever* policy probably allowed staff to safely approach more of the S&R equipment if needed, without breaching the electrical safety clearance distance to live equipment.

It also meant that the general public were also kept further away from any live equipment, e.g. in cases of cantilevers located right next to footbridge steps where people can be elevated to catenary and contact levels. (This is similar to that situation shown in *Figure 660*, but placing the cantilever on mast right next to the footbridge.)

In a support & registration arrangement, the catenary support insulators and contact pull-off insulators define the immediate electrical hazard zone. Refer to *Figure 210*. For Sydney's system, this "live" zone is at +1500V, and the safe working rules used to require that people were not allowed to approach within 1.0m of any live equipment. For accredited electric traction workers, the 1.0m clearance was relaxed to something much less, due to the fact that these people were trained and experienced to know the boundaries of the hazardous situations, and that they could put suitable and effective mechanisms in place that control the situation and restrict any encroachments to live equipment.

It is likely that the fault protection mechanisms for an "ac" system are still vastly superior to that of the "dc" system. It seems that the "ac" protection system is a lot more straightforward, more selective and offers better sensitivity. For example, *earth leakage protection* and *differential protection* schemes etc. for "ac" are able to detect and quickly isolate even small faults to the system (but these schemes are probably still not available for heavy current "dc" systems).

The "dc" protection system relies on *overcurrent* and *rate-of-rise of current* to trip the protection and isolate supply. Unfortunately, both of these mechanisms rely on some significant current being detected by the protection equipment, which may not always happen.

Exceptions

There are situations where this *dead cantilever* policy cannot be readily achieved. So for instance, Sydney's various OHW *tunnel cantilevers* are essentially *live cantilevers*.

In the case of a tunnel cantilever, the amount of exposed equipment probably doesn't matter because no one should be gaining access to the equipment when it's energized anyway (except maybe in cases where the equipment is installed back-to-back between tracks on a drop vertical for instance).

Also, it's unlikely any metallic object will drop onto the cantilever and become livened up, because a tunnel is usually a relatively inert and much better controlled environment from outside interference.

Besides, the overall size of a live tunnel cantilever frame is about 1/3 that of a normal cantilever (~1m or so instead of ~3m), giving less exposure in the first place.

Why PO Arms Need to be "Live"

If, as argued above, there are benefits to reducing the exposure of live equipment, then why are steel pull-off arms allowed to be operated "live"?

Pull-off arms need to be strong in tension, and so steel (or stainless steel) is the obvious choice of material to use.

With a steel pull-off arm, the connection to the contact wire places the entire arm at the same potential as the OHW conductors, i.e. normally at 1500V. Obvious.

The heel of a steel pull-off arm can come close to the outside edge of a passing pantograph, so the entire metal arm needs to be at the same electrical potential as the pantograph, i.e. +1500V.

The heel height (of 50mm, 100mm or the like) can help gain suitable mechanical clearances to passing pantographs, but for electrical clearances we need a minimum 150mm clearance. The heel cannot simply be raised higher to get better electrical clearances because this would

affect the OHW dynamics when a pantograph passes through, especially if there are medium to large contact radial loads taken by the arm (which then tends to lift the contact wire, and more so as a pantograph passes through).

Beyond the end of the arm, the rest of the registration assembly back to the support mast can be insulated/earthed as required for the dead cantilever policy.

Insulated pull-off arms, made with fibreglass rod or the like, don't have the above problem of electrical clearances – they only need mechanical clearance to pantographs at the heel end of the arm.

However, the population of insulated arms is extremely small in the network (they are mostly used inside a few tunnels, usually because of insufficient space for an alternative steel arm configuration).

There have been various issues with using insulated pull-off arms, so they are only reserved for special (awkward) situations. Issues included:

- The strength of insulation medium,
- Concern over bending moments applied to the insulation when taking high radial load,
- Excessive leakage currents if moisture somehow penetrates and "wicks" along the length of the insulation (in the case of fibreglass).

This 3rd reason is concerning as it can cause accelerated electrolysis corrosion in nearby metalwork, etc. without being immediately obvious.

Type 1A "Live" Boom

Sometimes the Type 1A or 2A live boom that holds the pull-off arms can cause potential problems.

An example of a highly undesirable situation is shown in *Figure 211*, where the boom (at 1500V) comes close to the opposite twin drop verticals which are at structure potential (~ earth). The clearance is estimated 250mm.

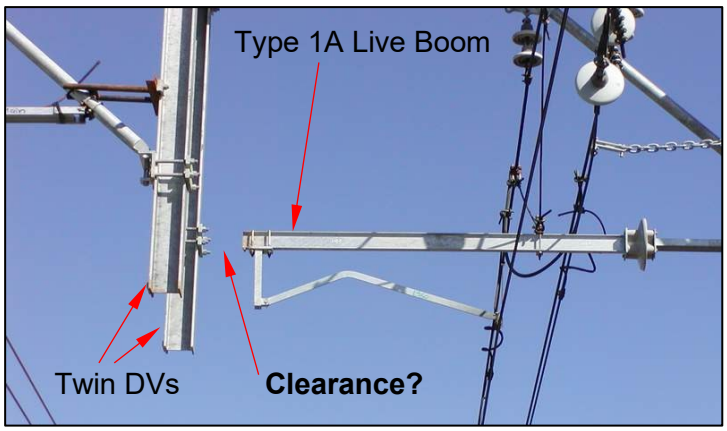


Figure 211 - Type 2A Live Boom close to adjacent DVs

In this case, the cantilever could/should have instead been installed on one of the left-side twin DVs, with a Type 1 cantilever (resulting in a positive radial load, which is more desirable in any case). Refer to the current Standards.

Other Issues

Spark gaps are no longer installed on all masts, only those identified as posing the most risk (e.g. where people are likely to congregate).

As argued above, this could be another reason why the limited exposure achieved with dead cantilevers offers a better outcome for Sydney's dc OHW system.

CANTILEVER CALCULATIONS FOR INSTALLATION

Portal suspension arrangements, as used in the old days of fixed-anchored OHW, were probably quite expensive, mostly because of the cost and inconvenience of installing a portal structure spanning 2 or more tracks. However, the actual S&R arrangements were fairly straightforward, mostly because of the simple vertical chain and copper cross-span

construction (on both the live and dead sides). It also provided ready adjustment to get the catenary and contact wires into their correct spatial location in relation to the tracks being serviced.

On the other hand, *cantilevers* are relatively easy to install on simple and relatively cheap masts, or on drop verticals between tracks. But their more complex make-up requires a *computer program* to generate the necessary bill of materials and other construction details, including nominating attachment heights of the various brackets, pipe lengths (in standard increments), hole selections, etc.

I believe the prescriptive nature of this process should be capable of cantilevers being built such that they require no further adjustment, within their tolerances of the design position of track. (However, some minor adjustments may be needed if the track alignment is way off.)

The physical make-up of a cantilever depends on the cantilever *Type* (1, 2 or 3) and the sort of structure it's mounted on (mast, portal leg or drop vertical). It also depends on the calculation and survey of several other important variables to get the necessary construction information to allow the cantilever to be installed accurately.

These site-specific variables are shown in *Figure 212*, and include:

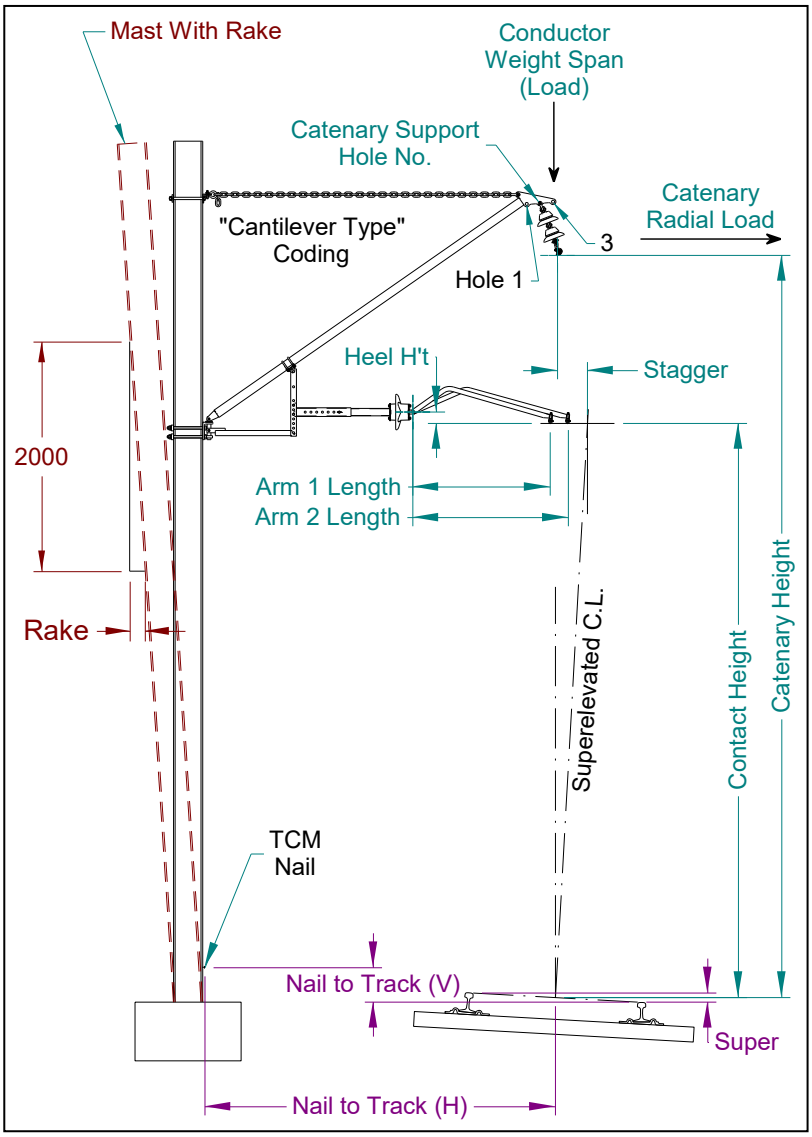


Figure 212 - Some Cantilever input variables

- The distance from the closest face of the mast to the design centre of track.
- The rake (lean) of the mast (over 2m vertical).
- The design track superelevation at that location.
- The weight of the conductor system to be held by the cantilever. (This requires the specific "weight span" to be calculated.)
- The calculated catenary radial load at that location.
- The preferred catenary suspension hole to be used. (Often there are 3 holes provided, for future lateral catenary stagger adjustment.)
- The catenary height. (This may be reduced leading up to overline bridges, or raised at level crossings.)
- The contact height. (This may vary as per the catenary height.)
- The contact stagger.
- Any non-standard pull-off arm selection (e.g. if longer arms are needed for clearance purposes).

- Any non-standard heel height.

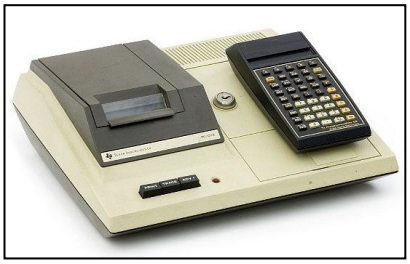
The various loads would be translated by the computer program into such things as insulator swing and mast deflection, which are then taken into account in the accurate design of the cantilever.

Computers

Apparently in the early projects that used cantilevers, line diagrams of the cantilever shapes were drawn to scale on paper, to help people determine the dimensional nature of each cantilever for each situation. This was laborious work, and prone to human error and interpretation problems. Every attempt was made to keep things as simple and "standard" as possible, in order to reduce the number of additional calculations needed, and to minimise the chance of human error (which could occur in any of the several stages from concept to design to construction).

In the late 1970s, rudimentary computers (although they weren't considered this at the time), were used to help automate the process of calculating each cantilever. The "Compucorp" as I recall, was one such desk-top computer (see photo to right). But its limited memory and printing capabilities still meant spending lots of design time on each cantilever. It was a valuable piece of equipment at the time, but I think it was mainly used for temperature/tension calculations, etc. and probably for various survey calculations.

In about 1980, programmable calculators were available that could accept algorithms to do the needed number crunching for each cantilever Type. Texas Instruments came out with the TI-58 and TI-59 programmable calculators. The TI-59 even had an in-built magnetic card reader which could allow programs to be stored and recalled conveniently. And both models could be attached to a printer cradle (see photo to right) that allowed narrow paper output to be sent to the field via facsimile machine.



Unfortunately, these TI devices did not have the memory capacity needed to model all the following variants of Mk-1 cantilevers, needed for Gosford to Newcastle Electrification project that was progressing at the time:

- Types 1, 1A, 1G, 1GA,
- Types 2, 2A, 2G, 2GA,
- Types 3, 3A, 3G & 3GA.

To cover all the arrangements, 2 or more programs were needed, and you had to swap them into the calculator depending on the cantilever Type to be processed – not very convenient.

A couple of cantilever programs were independently developed on the TI calculators that each had strengths. However, it soon became evident that a "standard" program was needed that did all cantilever Types, and that made this information available for complete wire runs and in a comprehensive and convenient output format.

In 1981, the Electrical Design Office was given access to the State Rail Authority's HP 3000 *minicomputer*, which was located in a special air conditioned room on the 1st floor at Transport House (above Wynyard Station). This was a much more powerful computer which was shared amongst various areas of the railways at the time. A single terminal, screen and large format dot matrix printer were set up in the design office, to be used for writing and running computer programs developed in the popular engineering "Fortran" language (short

for Formula Translater). This was used for survey, transmission line and overhead wiring applications, and a second terminal was eventually installed. A large plotter was later purchased, which was mainly needed for transmission line profiles and other survey work. The whole setup proved its worth in many ways back then.

At that time, I was given the job to write a program for the (then active) Gosford to Newcastle Electrification Project. The subsequent "Mast" program was written on the HP-3000 main frame computer, and it was completed in 1981. This program calculated the construction details for cantilevers in track pairs mostly (i.e. down and up tracks together) – an approach made necessary because the Type 3A cantilever had a span arrangement that linked with the Type 3 cantilever installed for the opposite track (see *Figure 217*). So, this required input information about both cantilevers in order to generate complete construction details for that location. The approach essentially generated OHW cantilever details for 2 runs – both the Down and the Up tracks together.

The program had 1,500 lines of Fortran code, and the output was sent to a large format (~A3) printer loaded with continuous paper (with perforated sides). The information was then "faxed" (a wonderful new technology at the time) to the construction depot at Morisset for subsequent construction of new OHW. This seemed to work well.

The lessons learnt from writing this program helped me to develop the much larger "CCalc" program for the Waterfall to Port Kembla Electrification Project. This program took over 1 year (on and off) to write and was completed in 1985. It had a massive 6,500 lines of Fortran code. *CCalc* was subsequently converted to the MS-Fortran programming language and issued as a DOS program, which allowed many more people to use it, wherever a PC was available.

I find it encouraging that CCalc is still in heavy use today, more than 35 years later, albeit with a somewhat primitive (but effective) text-based approach to input and output by today's standards. But, to my knowledge, it still remains very much a functional program, and is able to continually prove its value by saving time and benefitting in so many ways.

I often look back to those early programming days and the rather primitive (but still powerful) Fortran computer language, the work-arounds needed to fit code into the limited machine memory, and the basic tools available to write and debug programs. But it was all "new" and exciting stuff and importantly, it cut down the workload and provided huge gains in terms of efficiency and accuracy in OHW design work. We don't know how lucky we are today with modern computers, programming languages and sophisticated debugging facilities – luxury!

There'll be more to say on these 2 computer programs – "Mast" and "CCalc" – a bit later in this document.

"LIVERPOOL TO GLENLEE" CANTILEVERS

The OHW for Liverpool to Glenlee (Campbelltown) was *the first major regulated system* for Sydney. It had twin 137mm² contact wires supported by a single 270mm² catenary, and was commissioned into service in 1968.

This project needed cantilever arrangements installed mostly on simple masts, and that were capable of allowing the conductors to move longitudinally with wire expansion and contraction due to temperature change. Prior to this project, all OHW was fixed-anchored and mostly supported from steel portal structures with span wire construction, or to a much less degree, from "polygons". See *Figure 526* much later on for what these cantilevers look like.

A novel feature of the cantilevers was the use of twin stainless steel tubular pull-off arms, which were lightweight and supposedly didn't corrode over time. These were fittings 354/66-69, which were later changed over to fittings 354/76-79 to make them compatible with the standard 61/2 contact swivel clamp.

Figure 213 - Damaged PO Arm

I believe this contact clamp change came about due to eventual fatigue issues with the older rigid clamp – see *Figure 213* for an example of a failure of the old contact clamp causing the arm to slump (into the path of a train). The original contact clamp connection did not provide much freedom for the contact wire to move longitudinally with temperature changes, relying instead on the long arm lengths to minimise the rotational angle change at this vulnerable connection point. It probably didn't help that these tubes were crushed at both ends during manufacture, to become flat for connecting to the older contact clamp and with the pin insulator at the other end. The crushing action can cause stress corrosion which tends not to tolerate cyclic loading very well, thus accelerating the fatigue issue.

Figure 214 - Updated Pull-off Arms with connection to 61/2 Swivel Clamp

Anyway, the swivel nature of the current 61/2 contact clamp was the answer, as it provided the necessary rotational freedom of arm relative to contact wire, thus preventing fatigue. *Figure 214*.

Originally the heel end of the arms was installed onto the top of the vertically mounted pin-type insulators (the arms needed to be slightly longer in order to clear pantographs). As I understand it, these insulators were susceptible to corrosion and lightning damage, and so sometimes the insulator would snap from its mounted position on an insulator post and, held by its contact clamp connection, the arms and connected insulator parts would swing down and into the path of the next train to come along. Eventually these insulators were replaced by the standard post type insulator mounted with axis horizontal, as is current practice today.

I seem to recall that, for the sake of simplicity of construction, on *straight track* the catenary was installed with zero stagger and the contact wire was staggered ±250mm about this, to achieve its required zig-zag staggering pattern. When an overlap was reached, this approach could obviously no longer apply.

Recently there have been instances of the cantilever pipes rusting from the inside and finally showing their rust signs on the outside – see *Figure 214*. As far as I know, there is a program in place to renew the affected ones. That's not too bad for equipment that's been exposed to the elements for more than 50 years!

Refer to *Section 4.2.1* for more on these cantilevers & project.

"MARK-1" CANTILEVERS

I understand that these standard cantilever arrangements were developed in the mid to late 1970s for use on the "Loftus to Waterfall Electrification Project" (~1978 to 81), and later revised slightly for the "Gosford to Newcastle Electrification Project" (~1980 to 84).

The various cantilever configurations are shown as stick figures in *Figure 216* which provided a convenient reference and learning tool at the time.

Although there were some improvements made from previous designs, there were also a few significant problems that later became evident on some of the equipment.

Long stretches of lightly-curved track (notably around Ourimbah) required a large number of Type 2A cantilevers – one after the other – so as to deal with the medium-sized *negative* radial loads (the cantilever is shown in *Figure 219* a bit further on).

Unfortunately, this led to contact wire "hogging" (the contact wire rises towards mid-bay instead of being flat through the bay). The amount of hogging (up to 300mm from memory) and its extent over many successive bays, led to an operational problem for trains travelling at reasonable speed around the curves.

In particular, freight trains with their multiple, closely-spaced pantographs, caused the contact (and supporting catenary) to move wildly up and down in this area. The first pantograph made it through okay, but its disturbance on the contact caused the following pantographs to get progressively more chaotic with much arcing and disconnecting taking place. Field testing was carried out using 46-Class and 86-Class locomotives to try to get a handle on the problem and its cause – see *Figure 215* (note the graduated board on left image, for helping to assess the amount of contact wire uplift at that location).

Subsequent reports honed-in on the catenary tension being slightly higher than its design value, causing the hog. (This higher tension was due to an additional weight unit on the tension regulator weight stack.) In addition, the compressive contact radial load on the Type 2A "crank", when not perfectly perpendicular to the track, caused contact tension problems.

Steps were taken at the time to combat the problem, and it seemed to improve (although it's probably not perfect).

Fortunately, there are no longer any electric freight trains on the system. Also, the newer pantographs seem to provide a superior interface to the contact wire, in terms of being able to trace an imperfect contact profile, as well as more effectively dampening any oscillations set up, so that the last pantograph is not as badly affected.

More information is given below, in the section headed "*A Compressive Load Problem*".

Figure 215 - Testing of 46-Class (left) & 86-Class (right) Loco Pantographs at Ourimbah (1982)

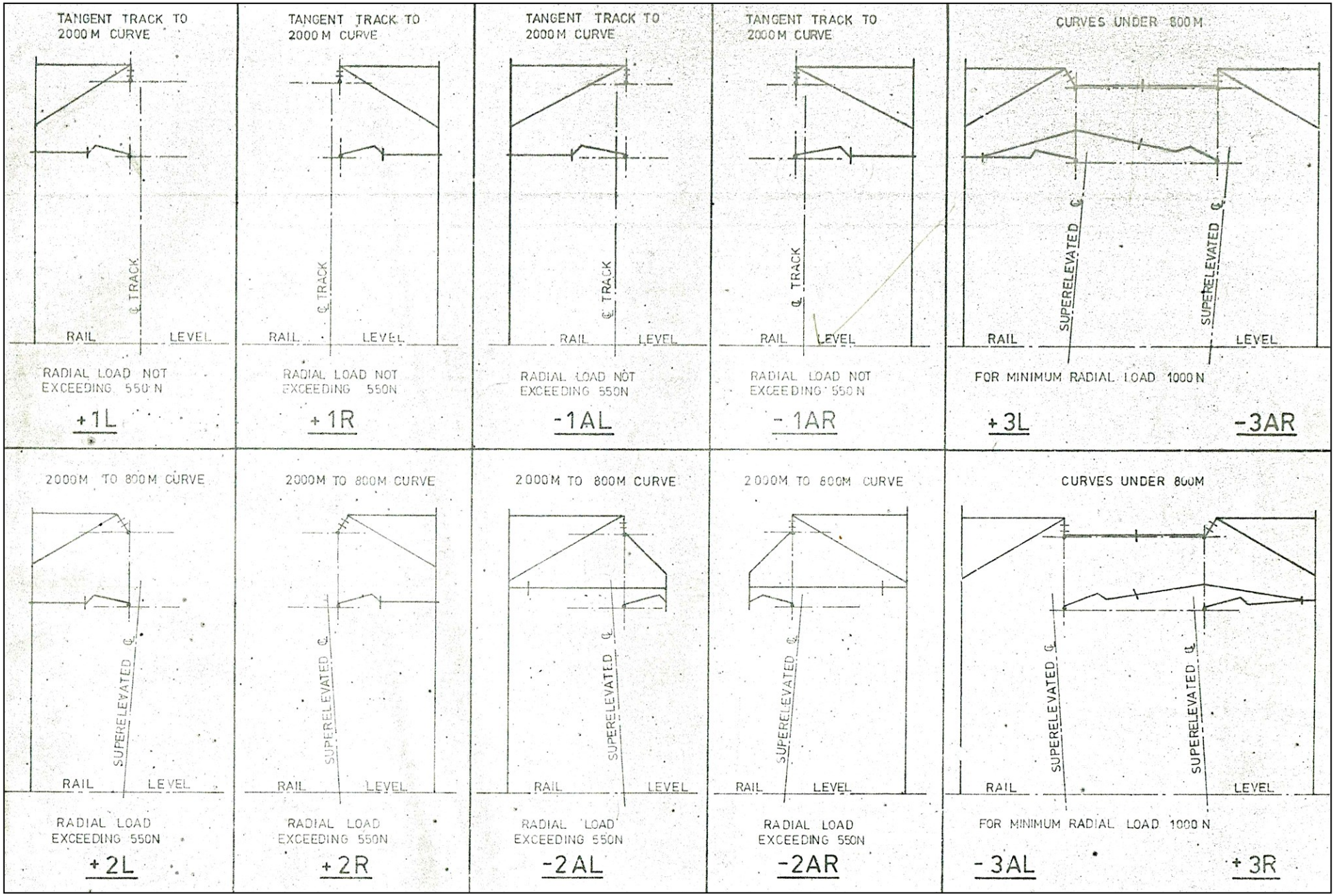


Figure 216 - Summary of In-Running Mark-1 Cantilever Types (Types 1G, 2G, 3G & 3GA for AirGaps omitted)

One of the features of this style of cantilevers was the use of "two-third spans" (called "Type 3A spans") for registering wire around tight track curves. See *Figure 217*.

Normally in this track situation, the catenary and contact wires change direction significantly at each support structure as the wire goes further around the bend, and this change in wire angle generates quite large radial loads at these registration points (on the pull-off arms and catenary support insulators).

Figure 217 - Type 3 & 3A Cantilever arrangements with 2/3 Span to opposite track

In the past the high radial loads typically necessitated the use of heavy portal structures, which have a steel bridge spanning the 2 main line tracks from the top of one mast to the opposite mast, and with knee-braces to help stiffen the structure. However, an alternative two-third span arrangement allowed the use of 2 simple masts, with span wires from the heavier gauge mast located on the outside of the curve taking all the conductor radial and wind loads for both tracks.

This approach was much less expensive than using portals. In fact, it was mentioned that, had it not been for the use of the two-third span arrangement, the extra cost involved in using the alternative portal structures may have prevented the Gosford to Newcastle Electrification project from being viable at that time.

Unfortunately, the significant down side to the two-third span arrangement is the loss of *independent registration* (it is a mandatory requirement to avoid cross-spans these days). The consequence of the many cross-spans was that damaged OHW over one track will more than likely stop trains on both tracks, which is a significant operational penalty.

Suitable Pipe Angles

The cantilever pipe is inclined at about 30° to the horizon. The actual angle depended on the chosen standard pipe length.

The "Mast" computer program generates the construction details for each Mk-1 cantilever. Starting at 23°, it finds the smallest standard pipe length (in increments of 250mm) so quite often the angle is less than 30°. The maximum angle is typically about 45°, although that limit didn't seem to be a major concern.

At the time, Civil Design had advised that 23° should be the shallowest angle for the cantilever pipe, otherwise the pipe and chain may, in certain highly loaded circumstances, become too highly stressed or buckle (I guess this is especially important in the long term if some corrosion sets in).

Cantilever Coding for Mk-1 Cantilevers

Mark-1 cantilevers saw the first use of a "cantilever coding" system for designing each instance of a cantilever. This coding approach allowed some fundamental characteristics of each site-specific cantilever to be described in the coding itself, and included "primary coding" and "secondary coding" elements. Up to 5 characters (elements) could be used to describe the cantilever primary coding.

Cantilevers were given "Types" depending on the amount of contact radial load imposed on the cantilever (i.e. how much the wire changes direction at a pull-off arm):

- ***Type 1*** – Suitable for straight track situations down to about 2,000m radius, where the only contact radial load on straight track was that caused by the zig-zag staggering pattern from structure to structure.
  For contact radial loads up to ±550N.
- ***Type 2*** – This was a medium radial load situation (typically with track curves from about 2,000m down to 800m radius.
  For contact radial loads from ±550N to 1,000N.
- ***Type 3*** – The highest radial load, caused mostly on tight curves of less than 800m radius, but could also exist in turnouts where the contact wire has a large change in direction.
  For contact radial loads greater than 1,000N.

In addition, there was a normal arrangement and an "Alternative" arrangement for each of the above 3 types:

- The ***normal*** arrangement had the radial load acting away from the support mast, which is quite a stable situation. This is a *positive contact radial load* situation. E.g. Type 1.
- The ***Alternative*** arrangement (using the suffix "A" in the coding) had the radial load acting towards the support mast (a compressive load), which can be less stable and more of a challenge to deal with, especially for enabling the right conditions for higher speed trains. This is a *negative contact radial load* situation, viz. Types 1A, 2A and 3A.

A further variant happened when the contact wire had risen to being out-of-running (usually 500mm above the in-running height of 5.2m). There was no need for the normal pull-off arm in this situation, as it was located well above the train's pantographs, so a simpler "straight arm" registration was possible. These arrangements were given the suffix letter "G" in the coding. E.g. Type "1G".

In addition, the type "GA" was the Alternate G arrangement. Note that types 1G, 1GA, 2G & 2GA all looked similar in appearance, however type 3G and 3GA were quite different.

So, there were the following 12 cantilever types:

- Types 1, 1A (in-running) and 1G, 1GA (out-of-running)
- Types 2, 2A (in-running) and 2G, 2GA (out-of-running)
- Types 3, 3A (in-running) and 3G, 3GA (out-of-running)

Cantilever Calculations for Installation

Portal suspension S&R arrangements (as used in the old days of fixed-anchored OHW) were relatively expensive, mostly because of the cost and inconvenience of installing a portal structure spanning 2 tracks. However, the installation of these support & registration arrangements was fairly straightforward, because the vertical chain supporting the catenary as well as the various cross-span constructions allowed ready adjustment to get the catenary and contact wires into their correct spatial location relative to the track being serviced. Very few calculations were necessary. But there would have been a lot of effort to "adjust in field".

On the other hand, *cantilevers* are relatively easy to install, mostly from masts (cutting down costs). However they require a computer program to generate the necessary bill of materials and other construction details, including nominating attachment heights of the various brackets, pipe lengths (in standard increments), hole selections, etc.

The big benefit of the computer program approach is that, provided the cantilever was properly designed and installed to the calculations, the contact wire should be in its correct spatial position (within its tolerance) relative to the design superelevated position of track. Therefore, there should in theory be no need for any time-consuming in-field adjustments. Local adjustment is available if needed to suit the existing position of track (although care needs to then be exercised with any changes).

The physical make-up of each cantilever depends on the cantilever Type and the sort of structure it's mounted on (mast, portal leg or drop vertical – or wood pole if required). It also depends on measuring or determining several other important variables to determine the cantilever shape and get the necessary construction information to allow the cantilever to be installed accurately.

These site-specific parameters are shown in *Figure 212*, and (in addition to the system parameters) include:

- The distance from the closest face of the support mast to the design centre of track.
- The rake (lean) on the mast.
- The design track superelevation at that location.
- The weight of the conductor system to be imposed onto the cantilever. (This requires the specific "weight span" to be calculated for that location.)
- The calculated catenary radial load at that location (the contact radial load is determined by the program based on the relative conductor tensions).
- The preferred catenary suspension hole to be used. (Often there are 3 holes provided, for future lateral catenary stagger adjustment.)
- The catenary height. (The design determines this, because it may need to be reduced leading up to overline bridges, or raised at level crossings.)
- The contact height. (This may vary – similar to the catenary height.)
- The contact stagger.
- Any non-standard pull-off arm selection (e.g. if longer arms are needed for pantograph clearance purposes at crossovers).
- Any non-standard heel height.

The various loads would be translated into such things as catenary insulator swing and mast deflection, which are taken into account in the design of the cantilever.

In the early projects that used cantilevers (pre 1980), apparently line diagrams were drawn to scale, and this often helped people determine the dimensional nature of each cantilever. This was laborious work, and prone to human error and interpretation problems. Every attempt was made to keep things as simple and "standard" as possible in order to reduce the number of additional calculations needed and reduce human error.

In the late 1970s, rudimentary computers were used to help automate the process of calculating each cantilever in a wire run.

In about 1980, programmable calculators were becoming available that could accept algorithms to do the needed number crunching for each Mark-1 cantilever "Type". Texas Instruments came out with the TI-58 and TI-59 programmable calculators. The TI-59 even had an in-built magnetic card reader which could allow programs to be stored and recalled conveniently, and both could be attached to a printer cradle that allowed narrow paper output to be sent to the field.

A couple of people (including self) had developed cantilever programs on the TI calculators, that each had their own strengths. However, it soon became evident that a single "standard" program was needed that did all cantilever "Types", and that made this information available for complete wire runs. It really needed a bigger computer program.

In 1981 I was tasked to write a program in the Fortran language for the Gosford to Newcastle Electrification Project, which was well under way at the time.

The subsequent cantilever program was called "Mast", and was written on the HP-3000 main-frame computer at Transport House in Wynyard. It was completed in 1981.

This program calculated cantilevers mostly in track pairs (i.e. down and up tracks together). This was done because the Mk-1 Type 3A cantilever had a span arrangement that linked it with the Type 3 cantilever installed for the opposite track (see *Figure 217*). So, this required input information about both cantilevers (including track centres), to generate complete construction details for that whole location.

The program had 1,500 lines of Fortran code, and the output was sent to a large format (~A3 size) printer loaded with continuous paper. The information was then "Faxed" (wonderful new technology at the time) to the construction depot at Morisset for subsequent construction of OHW. This mostly worked well.

The "Mast" Computer Program

The key to the effectiveness of the coding system was a dedicated computer program and several *standard cantilever arrangement* drawings. The computer program, called "Mast", determined the various parts needed and gave sufficient construction information to allow each cantilever to be accurately built.

Importantly, it was able to input the surveyed rake (lean from vertical) on each mast, and could predict the amount of deflection on the mast (due to cantilever loading) at the tie-rod, jib support and pull-off bracket positions. The combined effect of "Rake minus Deflection" on the mast at these 3 heights helped to accurately determine each cantilever make-up.

This program did away with the need to produce cross-section drawings for each location, which was previously the general approach adopted by the NSW railways, probably since day one. It also meant there was no further need to use primitive, time-consuming and relatively inaccurate graphical methods (pencil on graph paper) to determine the dimensions of the cantilever frame to erect for each location (which differed from location to location) – and there were lots of locations (something like 30 to 40 required per kilometre per track).

The advantage of the new computer program was that it saved time when producing a more complete design for a run of OHW. However, the down side was that constructors had to match the computer output with the appropriate standard arrangement in order to build the thing, then interpret the various information fields from the computer output. This took a little getting used to, but people soon understood how it worked and cantilevers were generally built as designed and in quite an efficient manner as it turned out. The construction engineers did a great job guiding their staff in the interpretation of the coding and standard

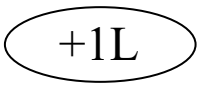
arrangements. They also insisted on providing feedback of any problems encountered, for subsequent investigation and resolution, so as to avoid a repeat of the same.

The Mast computer program produced output for both the Down and Up tracks at the same location (which was essential due the type 3 & 3A two-third span arrangements described above). If there was no opposite track, then this information was simply left blank.

This program was later rewritten in Microsoft Fortran *for the PC* for convenience (using the MS-Dos environment), which meant it could be used on a standard PC in the field for calculating emergency cantilevers.

Another computer program variation called "MastWood" was written specifically for adapting Mark-1 cantilevers to wood poles. This approach provided a relatively cheap d quick construction in non-critical areas of the network, and was especially useful during emergencies to get fallen wire back up in the air for train running. This program took into account the different diameter of the pole at the top and bottom (the taper of the pole), and the altered stiffness of the pole.

A *primary coding* was used to describe the fundamental shape of the cantilever, and this coding appeared inside an oval shape on the corresponding OHW layout at the required location. A typical primary coding is:



Secondary coding was optional, and was called up by an asterisk '*' at the end of the primary code, e.g. +1L*. If used, it allowed some deviation from predefined standard settings (catenary height of 7.3m, contact height of 5.2m, and stagger of 250mm, etc.). This extra coding appeared beneath or above the oval containing the primary coding. For example, deviations from standard might be:

A = 6.45m	(Catenary Height)
B = 5.05m	(Contact Height)
C = 954/53	(Pull-Off Arm fitting)
D = 100mm	(Heel Height)
E = +150mm	(Stagger)

Type 2A Problems

Of all the various cantilever arrangements, it was the type 2A that was the most troublesome.

It had to be set up correctly, otherwise it tended to twist the 250 UC mast that was supporting it (a Universal Column section is hopeless in resisting a twisting force). Sadly, in this situation any twisting on the UC further exacerbated the problem. It caused all sorts of out-of-balance loads on the cantilever/mast, and could progressively alter the tensions in the catenary and contact wires (depending on how far the cantilever had swung away from its neutral position 90° to the track). See next heading for more on this.

Also, the system depth (vertical height difference between catenary and contact wires at the support) required a special steel "Crank" for the 2.1m system depth, and needed other special length Cranks to deal with smaller (or larger) system depths, such as is needed leading up to an overline bridge.

Lastly, it was also awkward to properly set the 2 span attachments that stabilised the arrangement from the catenary wire.

It was this Type 2A arrangement more than any other, that was to receive particular attention for future improvements, that led to the "Mark-2" cantilever series. (Over the past three decades, the Type 2A cantilever in the Mk-2 series has proven to be quite a successful design in many ways.)

A Compressive Load Problem

A significant problem arose with both the Type 2A and 2G arrangements which cater for relatively high negative contact radial loads (i.e. loads acting towards the support mast).

The problem was not just the contact wire negative radial load, but more so the following:

a) The way this load was transferred back to the mast using a channel post attached to *one side* of the mast. In this configuration, the pivot point near the post type insulator was located at the end of this post, some 1.5m or so projected out from the mast (towards the track).

b) The fact that the contact wire moves longitudinally with temperature, up to ±500mm from some neutral (design) position, caused problems. In addition, the contact wire can stretch with time and cause a more serious alignment problem.

The result can be a twisted mast and a relatively awkward arrangement that is not that stable. Refer to *Figure 218* which is a picture of a Type 2G arrangement with its negative radial load twisting the mast.

Figure 218 - Mk-1 Out-Of-Running Cantilever twisting the Mast

I could not find a photo of a Mk-1 Type 2A cantilever exhibiting this problem. However, *Figure 219* shows a Type 2A cantilever behaving well because its attachment to the catenary and contact wires are correctly set normal to the track.

Figure 220 hopefully shows graphically why the twist occurs in this arrangement, and why it's a potentially big problem unless periodically kept in check.

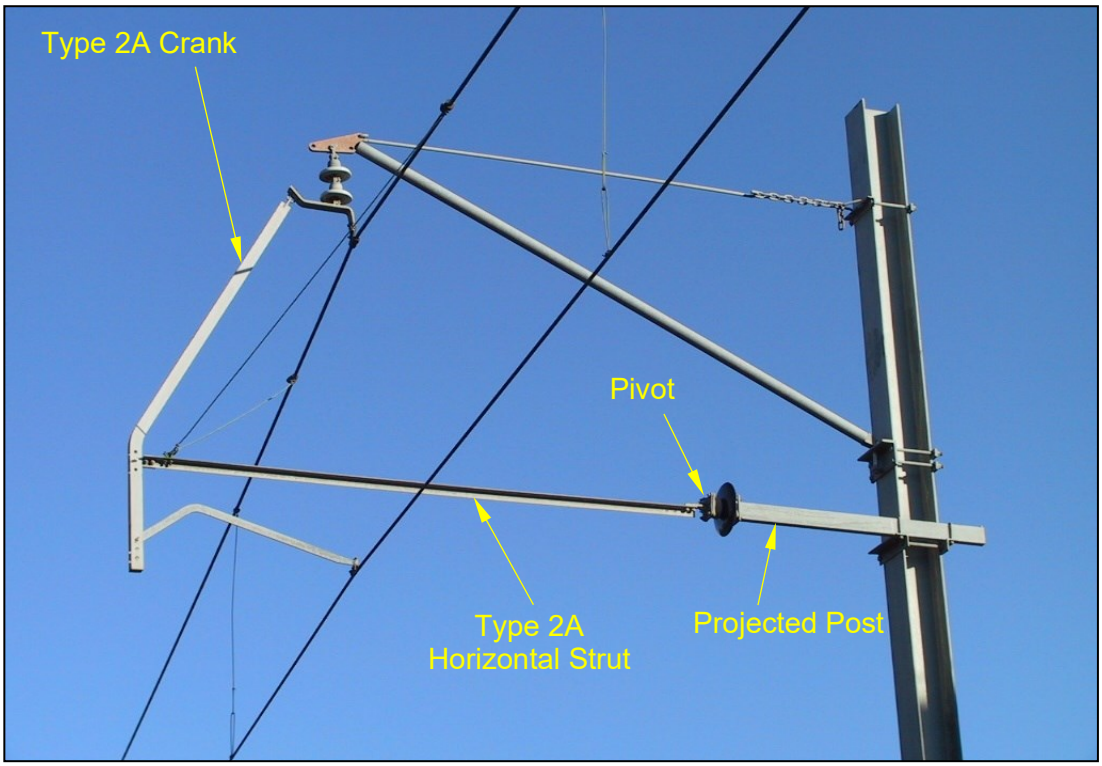


Figure 219 - Mk-1, Type 2A Cantilever with Insulator on Projected Post

Looking at *Figure 220*, the offset distance "d" in the diagram combined with the negative radial load causes a torque on the Universal Column (UC) mast that is not strong enough to resist without twisting.

Torque = Radial Load × Distance "d".

A UC steel section is extremely weak when subjected to torque, whereas a Square Hollow Section (SHS) is extremely strong in this regard (although it is much more expensive).

Any slight twist on this UC mast increases the distance "d", which then increases the torque on the mast, and so the mast keeps twisting until some equilibrium position (mast rotation) is achieved.

In the above process of mast twisting, the contact stagger reduces (a bad thing) and this in turn decreases the radial load (which turns out to be a good thing to reduce any further torque).

Importantly, the altered (reduced) stagger may have an adverse impact on pantograph security in both adjacent bays.

The other thing that happens here is that there is a slightly increased tension in one bay and less in the other adjacent bay, and this depends on the direction of the twisting. This effect is similar to that of "Tension Loss" which discussed in *Section 3.4.0.5, Tension Loss*.

With a series of Type 2A cantilevers all swinging the same direction (e.g. towards the tension regulator), there can be significant tension loss (or gain) back at the fixed anchor or fixed mid-point anchor, and this altered tension may affect the pantograph interaction.

It is possible that the mast can twist so much as to cause permanent structure deformation, which can weaken the structure (although I'm not aware that this has ever happened).

There are many of these arrangements from Gosford to Newcastle, and also some others located elsewhere in the system (although it's not a huge population).

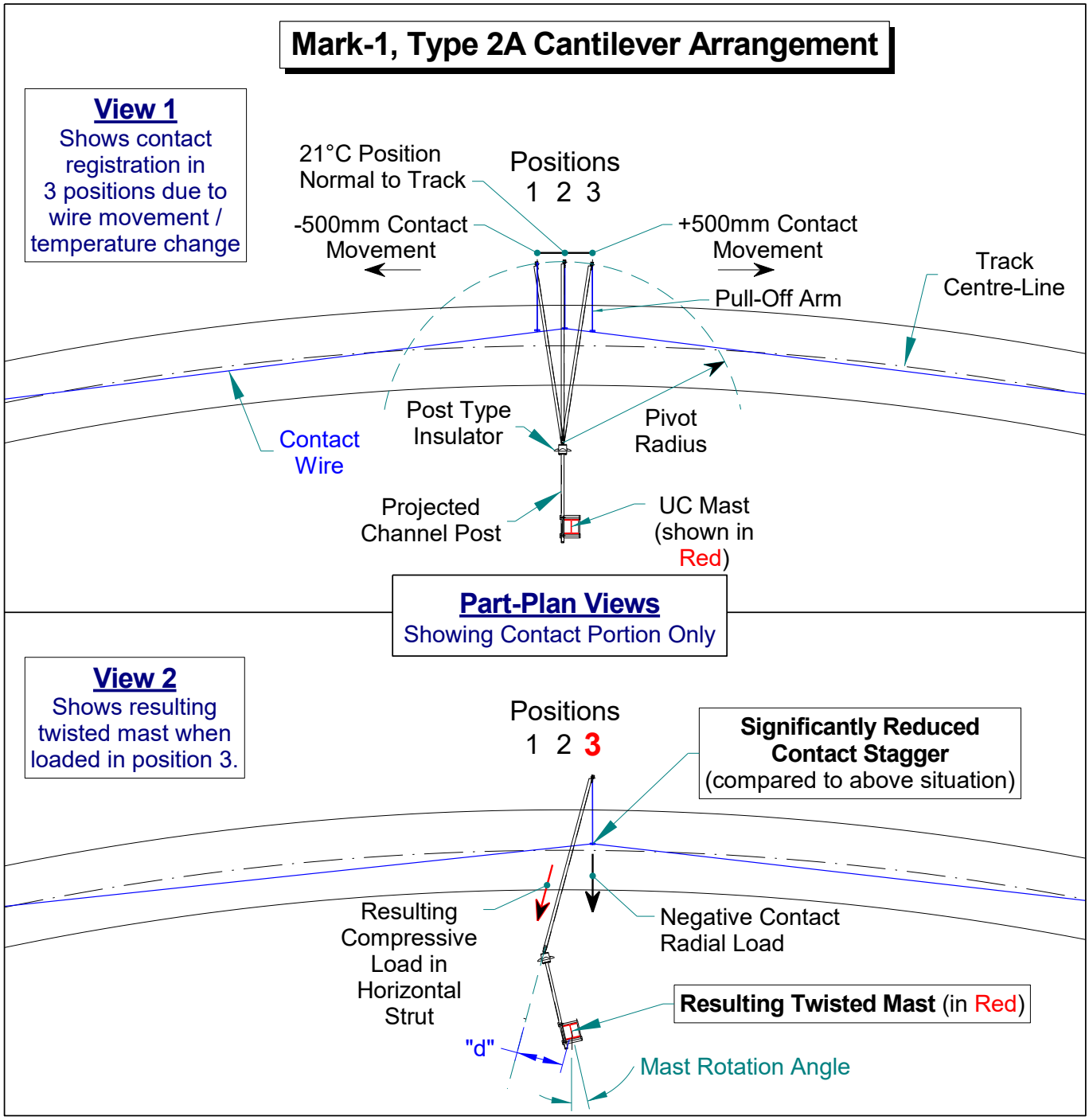

Mark-1, Type 2A Cantilever Arrangement
View 1
Shows contact registration in 3 positions due to wire movement / temperature change
21°C Position Normal to Track
Positions 1 2 3
-500mm Contact Movement
+500mm Contact Movement
Pull-Off Arm
Track Centre-Line
Contact Wire
Post Type Insulator
Pivot Radius
Projected Channel Post
UC Mast (shown in Red)
Part-Plan Views
Showing Contact Portion Only
View 2
Shows resulting twisted mast when loaded in position 3.
Positions 1 2 3
Significantly Reduced Contact Stagger (compared to above situation)
Resulting Compressive Load in Horizontal Strut
Negative Contact Radial Load
Resulting Twisted Mast (in Red)
"d"
Mast Rotation Angle

Figure 220 - Analysis of Mk-1, Type 2A Mast twisting problem

The bottom line here it that these arrangements can cause problems if not properly aligned, and they need to be checked from time to time to ensure they're not incorrectly set up for this excessive twist under temperature extremes.

Quite a long time ago there was talk of increasing the conductor tensions from Gosford to Newcastle in order to improve the relatively poor high-speed dynamic performance, but this action will have a detrimental effect on these arrangements (if you increase the tension, you increase the radial loads by the same proportion!).

Lastly, the newer Mark-2 Cantilevers totally removed this mast twisting problem by moving the pivot point back to the front centre of the mast, instead of being projected 1.5m towards the track *and* to the side of the mast. This also meant that the swing radius about the pivot point was greater, leading to less stagger change with regulated contact wire movement. Both

of these aspects offer significant improvements in the new arrangement. (Refer below, especially *Figure 223*.)

Refer to *Section 4.2.2* for further details on this type of cantilever.

"MARK-2" CANTILEVERS

In the early 1980s some significant changes were made to various aspects of OHW design. This came as a result of one or a few engineers travelling to Europe (in particular to France), and also overseas engineers coming to Australia (from France, England, South Africa, etc.). It was hoped that the exchange of information would subsequently help the NSW Railways gain a better appreciation and awareness of the problems and solutions experienced by other electrified railways, and in particular, what they were doing right and the current *industry best practice*, especially in terms of higher speed operation.

At that time, some areas of Sydney's network were experiencing significant problems with pantograph arcing, particularly at pull-off arms, and this was among the issues being investigated and discussed.

One important consequence of taking heed of industry best practice was the eventual adoption of *much tighter catenary and contact wire tensions* in the various future regulated OHW systems.

The catenary and contact wire tensions were increased as high as was deemed practical (while still maintaining a 3:1 safety factor in the catenary wire). This action resulted in far superior dynamic performance of pantograph / contact wire interaction, especially at higher speeds. (I think it also improved the current rating of the OHW.)

But as a consequence, the OHW support structures sometimes required thicker, stronger steel sections in order to cope with the higher mechanical loadings. Unfortunately, it's something that has since been the subject of criticism from time to time by some overseas "experts" (with accusations of "gold plating", over engineering, waste or the like) – see *Section 3.3.0.5*, *OHW Structure Size* for more on this and the vindicated outcome from a subsequent Value Engineering Study into the issue.

It was thus an opportune time to introduce an improved "Mark-2" series of cantilever arrangements for use on the (then new) "Waterfall to Pt Kembla Electrification" project beginning in about 1983.

This new series of cantilevers was needed to overcome some significant problems with the previous Mark-1 cantilevers (and prior to that, the Liverpool to Glenlee cantilevers), and the changes included some incremental improvements too. Significantly, they had to be strong enough to now deal with the increased radial loads (resulting from increased tensions).

Indeed, these arrangements have proven to be so successful that they are still being called up in new OHW designs today (more than 35 years later), with only a few minor improvements being needed along the way. So, they have turned out to be quite a robust design.

A big improvement to operational reliability came when cross-track spans were removed, as contrasted in *Figure 221*. This change helped to bring about *Independent Registration* throughout the various OHW runs, and this remains a fundamental requirement of any newly designed OHW. (Note that it obviously can't be achieved at crossovers.)

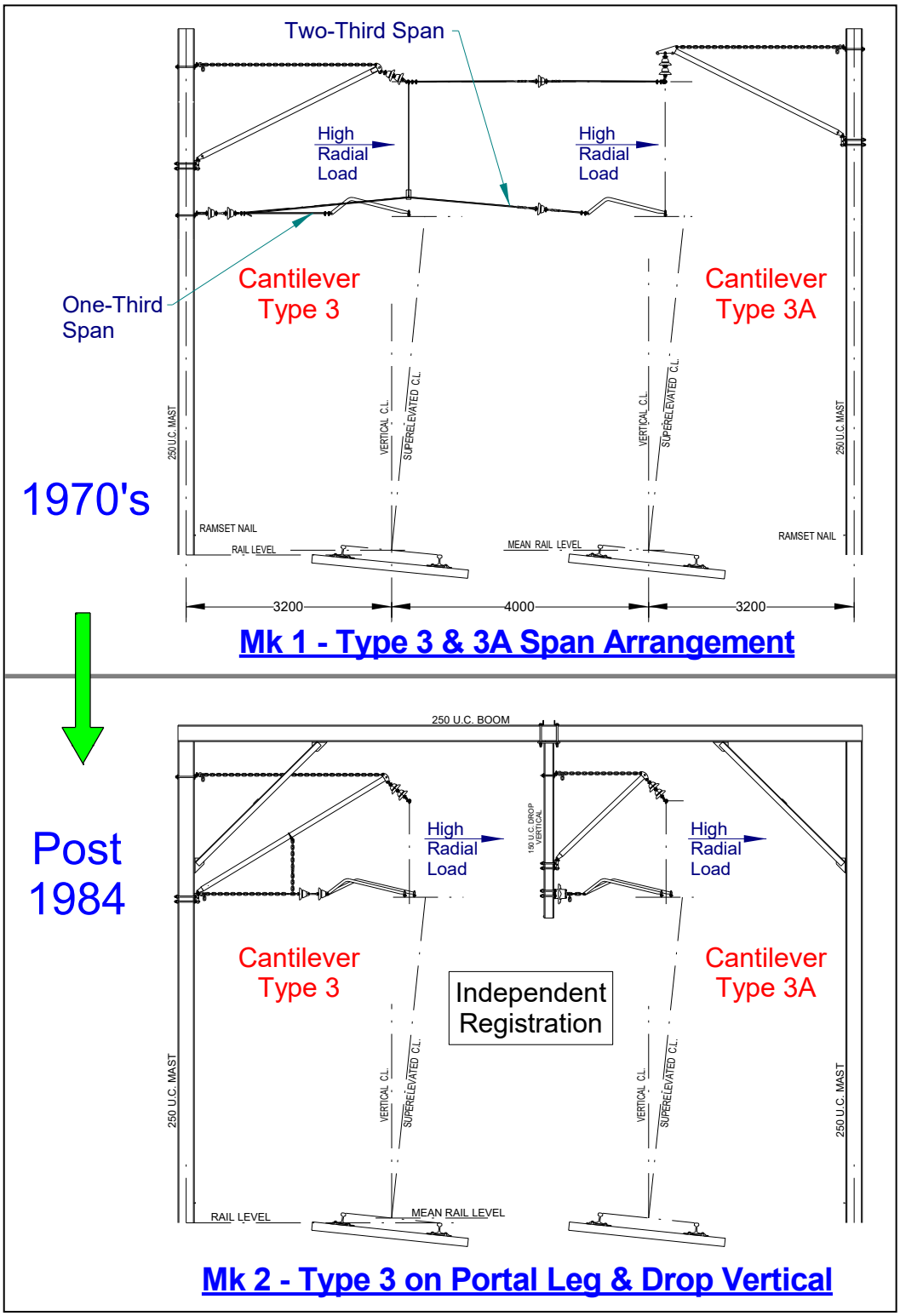


Figure 221 - Mk-1 "Two-Third Span" Cantilevers versus improved Mk-2 Cantilevers

One of the big changes was to design, as far as practical, any pivot points needed for regulated conductor movement to be close to the front face of the mast lining up with the centre of the front flange. In doing so, this would be a practical way to minimise any tendency to "twist" the mast due to conductor movement (with temperature) when registering significant radial loads. (The Type 2A cantilever of the previous Mark-1 series was a particular offender, as discussed above.) Refer to *Figure 222*.

Figure 223 shows how the pivot point back at the mast removes the previous Mk-1 Type 2A cantilever twist problem.

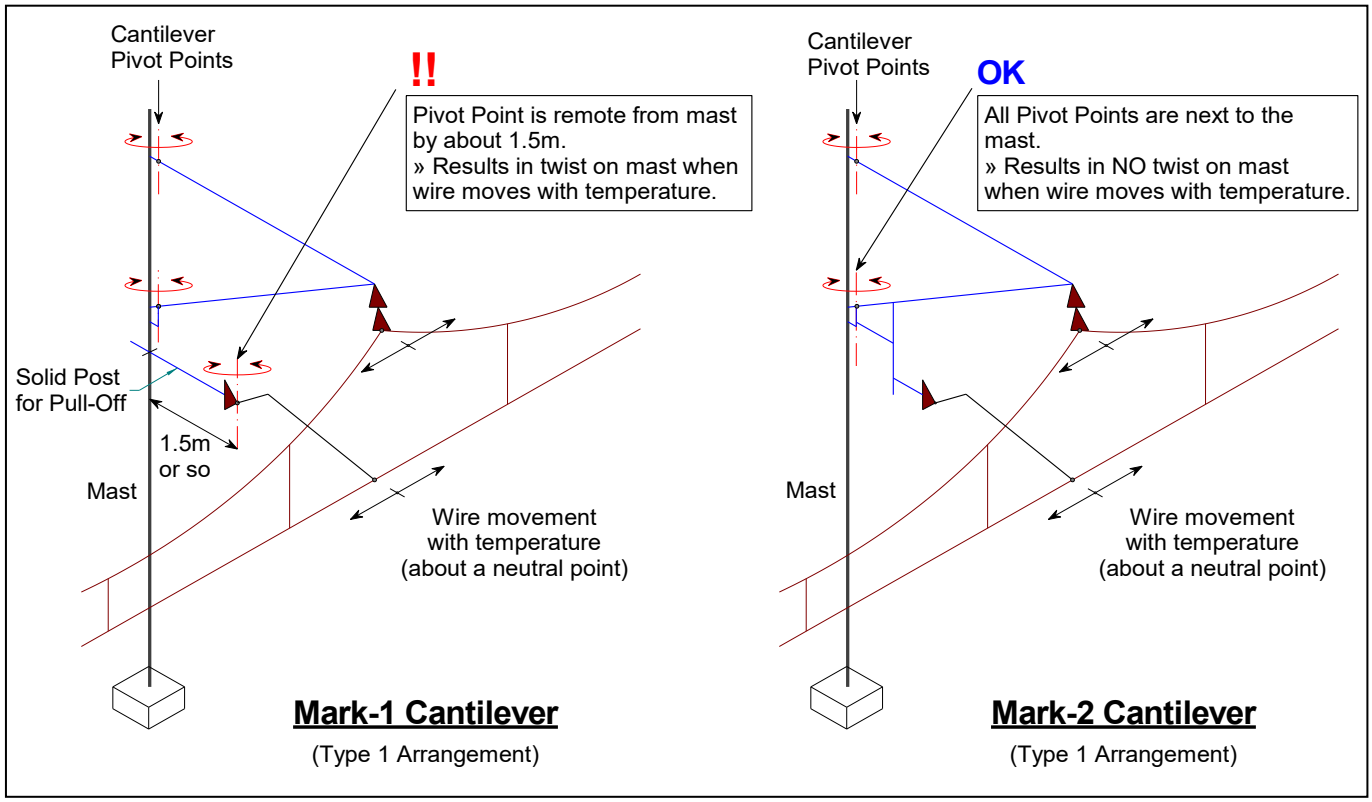

Cantilever
Pivot Points
!!
Pivot Point is remote from mast by about 1.5m.
» Results in twist on mast when wire moves with temperature.
Solid Post for Pull-Off
1.5m or so
Mast
Wire movement with temperature (about a neutral point)
Mark-1 Cantilever
(Type 1 Arrangement)
Cantilever
Pivot Points
OK
All Pivot Points are next to the mast.
» Results in NO twist on mast when wire moves with temperature.
Mast
Wire movement with temperature (about a neutral point)
Mark-2 Cantilever
(Type 1 Arrangement)

Figure 222 - Pivot points for Mk-1 versus Mk-2 Cantilevers

Unfortunately, the Type 1 & 2 cantilevers on a drop vertical have one of their configurations with the pivot point located some 400mm or so further out (at the heel of the pull-off arm), but this always has positive radial load and so should not pose a twist problem.

When compared with all previous OHW systems with lower tensions, the new Mk-2 system provided vastly superior performance (pantograph/contact interface performance at speed), and also provided a significantly higher current rating (refer to *Table 8* much further back).

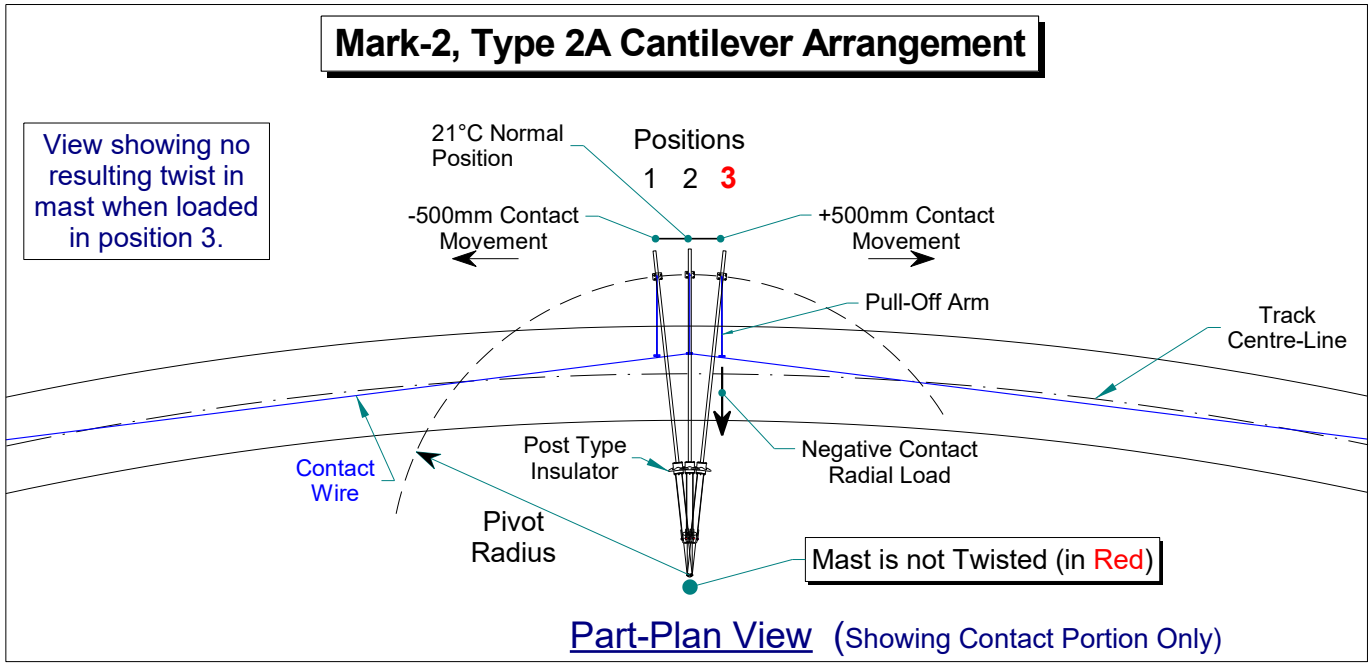


Figure 223 - Analysis of Mk-2, Type 2A Cantilever showing no twisted Mast

"Types" of Cantilevers

Below is a summary of all the various *Types* of cantilever configurations for the current Mk-2 cantilever series.

The *fundamental* arrangements have positive contact radial loads (acting in a direction away from the support structure), which determines the cantilever Type *Number*, namely:
→ Types *1*, *2* and *3*.

There are *Alternative* arrangements that help deal with *negative* contact radial loads (acting towards the support structure). Thus, there are also:
→ Types *1A*, *2A* and *3A*.

There are the "*G*" arrangements, for taking the contact wire about 350mm to 600mm up and out-of-running at an overlap, needing a different sort of pull-off arrangement to handle both positive and negative radial loads (except Type 3 negative) – these use the symbol "G" (from the old term for overlap – airGap). They are:
→ Types *1G*, *2G* and *3G*.

There are also *Suspension* arrangements that do away with the cantilever frame and rely instead on catenary support via simple chain from a portal bridge or the like. They're limited to being within 100m of a fixed anchor or fixed mid-point anchor location. They are:
→ Types *1S*, *2S* and *3S*.

Lastly, there's the type "*G*" that supports the out-of-running contact wire at an overlap but using the simpler (cheaper) *Suspension* configuration instead of cantilever frame. Namely:
→ Types *1GS*, *2GS* and *3GS*.

I refer to *Figure 224*, which shows the various above combinations of cantilever Types for the current Mark-2 series.

For each of the below 3 conductor configurations, there is a set of 11 design drawings (listed in *Figure 224*) that describe the exact configuration of all the above cantilever Types ...

- Single Catenary / Single Contact,
- Single Catenary / Twin Contact, and
- Twin Catenary / Twin Contact.

Cantilever Coding for Mk-2 Cantilevers

The Mark-2 cantilevers continued with the efficient use of a cantilever coding system for designing each instance of a cantilever. However, the new coding system was expanded to allow a more precise description of not just the cantilever but also the structure it was to be mounted on. Now up to 9 characters (elements) can be used to describe the cantilever, all located within an oval symbol on the OHW layout.

Refer to *Figure 225* for details of the make-up of this Mark-2 cantilever coding system.

A typical *primary coding* is:

Secondary coding was fundamentally the same as for Mark-1 cantilevers, (needed if there's something non-standard), and called up with an asterisk '*' suffix (as shown above).

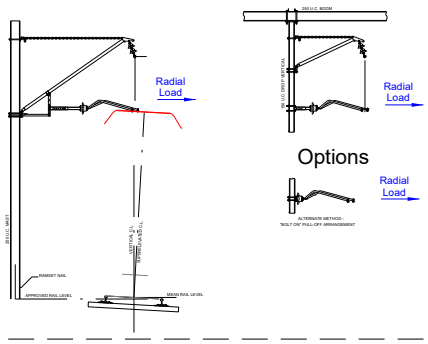
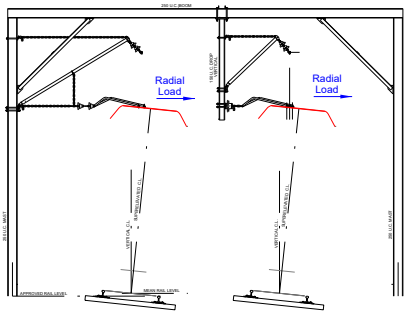
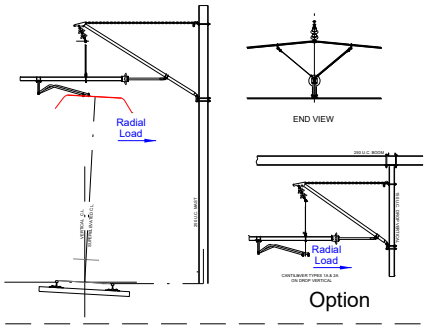
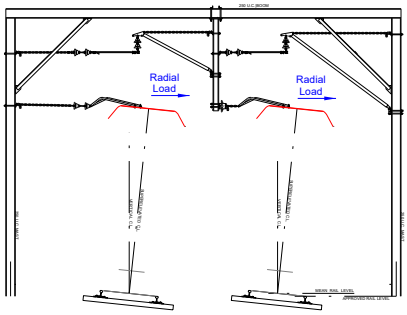
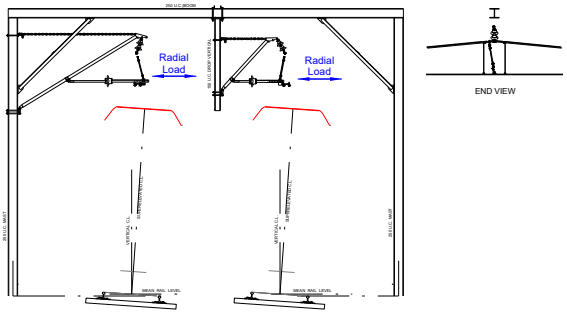
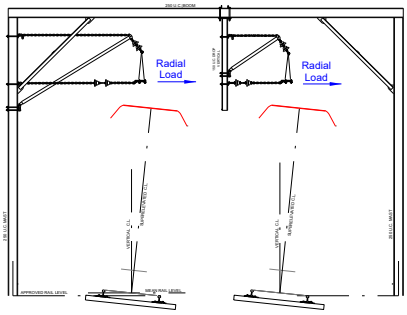
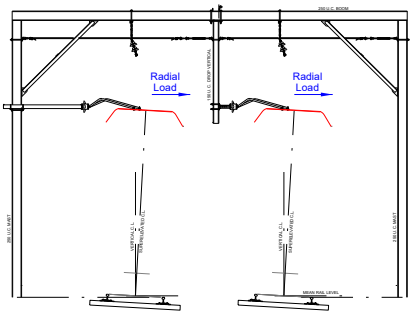
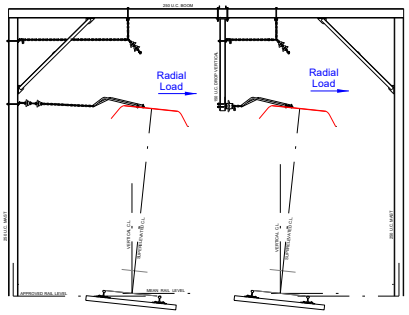
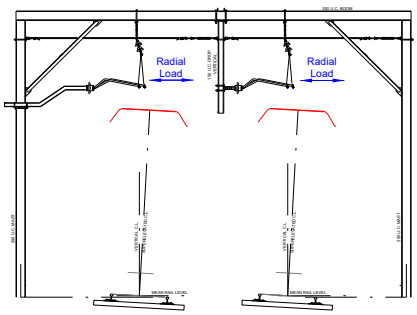
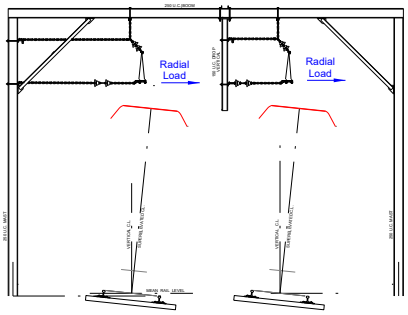
Mk-2 Cantilever Arrangements	**Types 1 & 2** For Small to Medium Radial Loads	**Type 3** For Large Radial Loads
Cantilever **Normal** Positive Radial Load (Acting Away from Support Mast)	**1, 2** 	**3** 
Alternate Negative Radial Load (Acting Towards the Support Mast)	**1A, 2A** 	**3A** 
Air-Gap (Overlap) Contact Wire is Lifted Up Out-Of-Running	**1G, 2G** 	**3G** 
Suspension **Normal** Supported From Portal Bridge With Suspension Insulators. Positive Radial Load (Acting Away from Support Mast).	**1S, 2S** 	**3S** 
Air-Gap (Overlap) Supported From Portal Bridge With Suspension Insulators. Contact wire is Lifted Up Out-Of-Running	**1GS, 2GS** 	**3GS** 

Figure 224 - Mark-2 Cantilever summary (OHW System 2: Single Catenary / Twin Contact)

Example:

A = 6.45m	(Catenary Height)
B = 5.05m	(Contact Height)
C = 954/53	(Pull-Off Arm fitting for single contact system)
D = 100mm	(Heel Height)
E = +150mm	(Stagger)

Added information was also available to prescribe some characteristics of the cantilever to be produced. The "F" letter calls this special requirement up, e.g.

F = Pipe (1.75m)	(Special pipe length required)

As may be appreciated in *Figure 225*, with only 26 alphabetic characters available, it was quite a challenge to describe what needed to be described in the coding in some logical way, but without doubling-up on any particular character. This approach was needed so there could be no ambiguity of what each element letter meant.

The last 7 alphabetic characters – 'T' to 'Z' – were reserved for describing the mast structure or DV size (with 'Z' meaning none of the above standard sizes, so need to specify elsewhere).

Indeed, it was impossible to cater for absolutely every scenario, but if things became too complicated, then a cross-section would need to be drawn up and referenced on the OHW layout, for use during construction and later during maintenance. Fortunately, over the past few decades, the need for such cross-sections has mostly proven to be minimal.

CCalc Input Sheet

To help gather the necessary input information for subsequent entry into the CCalc program, a CCalc Input *spreadsheet* was developed. It also provides a good summary of the entire OHW run and the wire characteristics for that project.

Figure 226 is one such completed input sheet, which was taken from one of the track reconfiguration stages of the Chatswood to Roseville OHW upgrade (which was part of the "Epping to Chatswood Rail Tunnel Interface Works" being progressed around 2005).

Each row in the main section represents a cantilever to be calculated, apart from the "Start" and "End" of the run, and any other non-cantilever *support* location (such as at bridges) to help with calculating the needed weight spans, etc. for legitimate cantilevers. (The information is also useful for entering into the dropper program.)

In terms of the coloured backgrounds …

- User entries are made into the cells with *white* background.
- Information with a *green* background was calculated based on the input.
- Cells with *blue* background indicate something to be aware of (in the 2 cases shown, it highlights that the contact wire ramp rate may be too great – but here it was in conjunction with an overlap bay, which is quite OK).

The formulas behind the green cells are there to reduce the number of calculations needed and to provide accuracy. They are also able to detect input errors with immediate feedback so they can be corrected (such as input number is *out-of-range*). Certain other white cells also check the entered number entries for valid range, and highlight if potentially out-of-range.

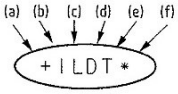
It's only the information from the columns in the left two-thirds of the sheet that are entered into the CCalc program.

CODING DESCRIPTION

ELEMENT	ASPECT	CODING CHARACTER DESCRIPTION	EXAMPLES
(a)	STAGGER DIRECTION	STAGGER DIRECTION: "+" = STAGGER DIRECTED TOWARDS THE PULL-OFF STRUCTURE (REL. TO TRACK SUPER C.L) "–" = STAGGER DIRECTED AWAY FROM THE PULL-OFF STRUCTURE (BLANK) = ZERO STAGGER	+1LMV –1ARMV 1LMV
(b)	CANTILEVER TYPE	(see table below)	+**1GS**VLDT* -**1A**RMV +**2S**VLDT* -**2AR**MV +**3**LMV -**3A**PVLDT*
(c)	PULL-OFF SIDE	"L" FOR PULL-OFF STRUCTURES ON LEFT SIDE OF TRACK (WITH BACK TO SYDNEY) "R" FOR PULL-OFF STRUCTURES ON RIGHT SIDE OF TRACK (WITH BACK TO SYDNEY)	+1LMV +1RMV
(d)	STRUCTURE TYPE	"D" - DROP VERTICAL "M" - MAST STRUCTURE "P" - PORTAL STRUCTURE	+2LDT +2LMV +2LPV
(e)	STRUCTURE SIZE	"T" - 150 UC "X" - 254x89 D.C. "U" - 200 UC "Y" - 305x89 D.C. "V" - 250 UC "Z" - NOT LISTED "W" - 310 UC	+1LDT* +2LMV +2LMZ*
(f)	MODIFICATIONS "*"	> "A" = CATENARY HEIGHT (m) > "B" = CONTACT HEIGHT (m) > "C" = PULL-OFF ARM/S > "D" = HEEL HEIGHT (mm) > "E" = STAGGER (mm) (MEAN STAGGER FOR TWIN CONTACT) > "F" = SPECIAL (SPECIFY A PIPE LENGTH, PIPE ANGLE OR JIB SUPPORT BRACKET HEIGHT - SEE EXAMPLE) > "I" = SEE CROSS-SECTION (SHOW DRAWING No. ON LAYOUT - SEE EXAMPLE)	A = 6.55 B = 5.05 C = 955/21, 22 D = 75 E = 350 F = 2.75m PIPE I = EL0499037

TYPE	CONTACT RADIAL LOAD (SEE NOTE 6)		HEEL HEIGHT
	SINGLE CONTACT	TWIN CONTACT (TOTAL)	
1, 1G, 1S, 1GS	0 to 0.6kN	0kN to 0.8kN	100mm
1A, 1G, 1GS	0 to -0.6kN	0kN to -0.8kN	100mm
2, 2G, 2S, 2GS	0.6 to 1.2kN	0.8kN to 1.6kN	50mm
2A, 2G, 2GS	-0.6kN to -1.2kN	-0.8kN to -1.6kN	50mm
3, 3G, 3S, 3GS	1.2kN to 5kN	1.6kN to 5kN	50mm
3A	-1.2kN to -5kN	-1.6kN to -5kN	50mm

EXAMPLE ON OHW LAYOUT:



A=5.60
B=4.90
C=955/23, 24
E=+300

NOTES:

1. DIMENSIONS, FITTINGS AND ARRANGEMENT DETAILS ARE SHOWN ON CANTILEVER STANDARD ARRANGEMENT DRAWINGS - REFER TO LAYOUT SHEET FOR DRAWING NUMBERS. (CANTILEVER STANDARD ARRANGEMENT DRAWING SERIES IS NOW SHOWN AT SYDNEY-END ANCHOR FOR THE WIRE RUN).
2. CODING OF CANTILEVER ARRANGMENT IS REFERENCED WITH BACK TO SYDNEY.
3. IN THE CASE OF NO PULL-OFF STRUCTURE, THE CODING STILL REQUIRES AN "L" OR "R" REFERENCE IN ORDER TO SET THE STAGGER DIRECTION, EG. "+1LDZ*" (F=No P.O. STRUCTURE)
4. FOR TWIN CONTACT SYSTEM CONTACT RADIAL LOAD IS TOTAL COMBINED RADIAL LOAD.
5. REFER TO "CCALC" USERS MANUAL FOR MORE DETAIL ON ELEMENTS OF THE CODING SYSTEM, DEVELOPING "CCALC" INPUT SHEETS AND INTERPRETING THE OUTPUT OF THE "CCALC" COMPUTER PROGRAM.
6. REFER TO NOTES ON CANTILEVER STANDARD ARRANGEMENT DRAWINGS FOR LIMITATIONS ESPECIALLY REGARDING RADIAL LOADS AND WEIGHT LOADS.

RELEVANT "MARK 2" CANTILEVER ARRANGEMENT DRAWINGS

OHW CONFIGURATION	No. OF SHEETS	EDMS DRAWING No.	(EQUIVALENT SRA DRAWING No.)	COMMENTS
SINGLE CATENARY/TWIN CONTACT	11	EL0194773 to EL0194783	-	PREVIOUS CANTILEVERS WERE ON A1/89232 SH.1 TO 11
TWIN CATENARY/TWIN CONTACT	11	EL0003384 to EL0003394	A1/89233 SH.1 to 11	-
SINGLE CATENARY/SINGLE CONTACT	11	EL0006173 to EL0006183	A1/86719 SH.1 to 11	-

WARNING SCANNED IMAGE

A ORIGINAL ISSUE

RailCorp
ENGINEERING & PROJECTS GROUP
Professional Services Division
ELECTRICAL DESIGN

DRAWN J.M.
DESIGNED
DRG CHECK G. Cavallaro
DESIGN CHECK
APPROVED W. Leung 8.10.10

GENERAL
RAILWAYS OVERHEAD WIRING
MARK 2 CANTILEVER (CCALC) CODING DETAILS ©

FILE No. F2010/9879 | SHEET 1 OF 1 | A3
STATUS: CURRENT
EL0172074 | A

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Figure 225 - Mark-2 Cantilever (Ccalc) Coding details

"CCALC" Cantilever Program — Data Coding Sheet

	Location	Track	Mast Coding	Hole	Track CL to Mast Face (m)	Mast Rake (mm)	Track Super (mm)	Weight / Wind Span (m)	Catenary Radial Load (kN)	PO Structure to Track [3A & DV] (m)	Nail to Rail (m)	Nail to Boom (m)	Modifications: A. Caty H't (m)	B. Cont H't (m)	C. Arms	D. Heel Ht (mm)	E. Mean Stagger (mm)	F. Special	H. Wider Knee Brace	I. See Cross-Section
0.	MH11+928		Start										5.670	5						
1.	MH11+957	D	1SVLPW*	-	3.014	-	0	32.7 / 35.	-0.27	-	0.289	7.212	5.500	4.8	954/54		0			
2.	MH11+990	D	+1LPW*	2	2.746	-	0	31.6 / 31.	0.25	-			5.500	4.85			250			
3.	MH12+016	D	+1SULDT*	-	1.800	-	32	29.3 / 30.	1.00	0			5.464	4.85			250			
4.	MH12+046	D	+1SULDT*	-	2.300	-	45	29.6 / 28.5	1.53	0			5.467	4.85	954/53		250			
5.	MH12+079	D	1SURDT*	-	2.100	-	10	25.1 / 31.5	0.26	0			5.409	4.85	954/54		0			
6.	MH12+109	D	+1SURDT*	-	2.100	-	55	36.4 / 31.5	1.75	0			5.727	4.85			250			XXXXX
7.	MH12+139	D	+1SURDT*	-	2.100	-	14	36.6 / 30.	0.60	0			5.748	4.85			250			XXXXX
8.	MH12+167	D	+1SURDT*	-	2.100	-	0	21.2 / 29.	0.17	0			5.410	4.85			250			
9.	MH12+198	D	+1SURDZ*	-	-	-	0	26.4 / 29.5	0.00	0			5.492	4.85			20	omit PO		
10.	MH12+228	D	SUSP	-	2.000	-	0	28.6 / 30.5	0.29	0			5.759	4.85			200L			XXXXX
11.	MH12+258	D	-2ARDT*	2	1.853	-	-46	46.2 / 29.5	-1.67	-6.872			6.200	4.9			-300			
12.	MH12+295	D	+2LDT*	2	2.501	-	36	27.4 / 33.5	1.35	6.917			5.800	4.9	954/75		250			
13.	MH12+339	D	-3SVRDT*	-	2.102	-	38	24.2 / 22.5	4.22	3.816			5.700	5.25	954/54		-50			
14.	MH12+390	D	End										7.000	6						
15.																				
16.																				
17.																				
18.																				
19.																				
20.																				

Supplementary Information

	Radial Load Factor	Bay (to Next Location) (m)	Track Grade	Nail Vertical Distances: RL of Portal Boom	RL of Nail	RL of Track Low Rail	Vertical C.L. Track to Face of D.V.	Ramp Rate (1 / X)	Comment
0.		41	377						
1.	-0.0116	29	377	127.512	120.3	120.011		580	
2.	0.0109	33	377					Flat	
3.	0.0431	27	377				1.692	Flat	
4.	0.0664	30	377				2.148	Flat	
5.	0.0111	33	377				2.066	Flat	
6.	0.0757	30	377				1.914	Flat	
7.	0.0259	30	377				2.053	Flat	
8.	0.0075	28	377				2.100	Flat	
9.	0	31	377				#VALUE!	Flat	
10.	0.0126	30						600	
11.	-0.0724	29	-540				2.010	Flat	
12.	0.0585	38	-540				2.378	109	
13.	0.1826	45	-540				1.963	60	
14.									
15.									
16.									
17.									
18.									
19.									
20.									

Blank = Flat

Notes :

OHW System Details

Tension Mode (Reg., Fixed)		Regulated
Catenary :	Size (sq.mm.)	270
	Tension (kN)	23.1
	Std H't (m)	6.500
Contact :	Size (sq.mm.)	193
	Tension (kN)	18
	Std H't (m)	5.000
System :	Weight (N/m)	42.0
	=> T/w (m)	550.0

Area Description : CHATSWOOD TO ROSEVILLE
Track : Down North Shore - Stage 3
Filename : MHDS011A.CCA

Figure 226 - Completed CCalc Input Sheet for one Wire Run

The last 9 columns headed "Supplementary Information" are not entered into CCalc – they are there to enter other details that can help calculate the numbers needed for CCalc (to their left), and to give feedback regarding any potential errors. For instance, Radial Load Factor (RLF) is a number that's accurately generated on the OHW layout at each S&R location, to be entered here – it then calculates the Catenary Radial Load for the 9th column.

Figure 227 - Type 1 & Type 1A (distant) Mk-2 Cantilevers (Dapto to Kiama)

The "*CCalc*" Computer Program

Because the primary coding for the Mark-2 cantilevers was more prescriptive than for the Mark-1 cantilevers (9 elements compared to only 5), and there were many more standard cantilever arrangements to model, this required a totally new computer program to be written, with more detailed modelling and vastly more complicated algorithm.

Due to previous experience with writing the Mast program, I was asked to write this new program. It took just over 1 year to develop and proof test. But this time it had 6,500 lines of Fortran code, which was a huge program (particularly in those early days). Several tricks had to be employed to do all that was needed in, what was then, still a relatively small available memory space. At the time (1985), this program was considered to be at the forefront of computer-aided OHW design technology – how things have changed since then.

One privilege for writing the program was to give it a name. I chose "CCalc". It was going to be called "CantCalc" (for Cantilever Calculations), but I thought that name gave negative connotations. Besides, typing "CCalc" required 3 less characters to start the MS-DOS based program (and I don't know how many thousands of times I've typed the word "CCalc" to start the program over the years!).

Like most programs, it required *Input* to perform *Calculations* on and produce *Output*. The typical Input format is shown in *Figure 226*, and some typical Output is shown in *Figure 229*. Refer to the "CCalc Users Manual" for more information. *Figure 230* is a sample of one of the pages from this manual, showing how to interpret some of the rows of output information.

The CCalc program was developed to model all the various Mark-2 cantilever standard arrangements, as detailed below.

There are 3 standard wiring configurations, namely:

- Single Catenary / Single Contact,
- Single Catenary / Twin Contact and
- Twin Catenary / Twin Contact.

For each of the above configurations, there are 11 standard drawings, and each drawing has 2 standard cantilevers documented on it = 22 standard arrangements. So, this totals some 66 different standard combinations! Refer to *Figure 224* for the complete range of cantilever types for the Single Catenary / Twin Contact OHW System.

CCalc modelled all of these standard arrangements as accurately as was deemed practical at the time. This included calculating the *Rake* (easy) and *Deflection* (not so easy) due to the various OHW Loads on the mast, at the 2 or 3 mast attachment bracket heights – depending on the cantilever configuration (Tie-Rod bracket, Jib Support bracket and Pull-Off bracket).

The program also had to know about various "standard" impediments, such as the knee-brace mid-batten/s. These are 1 or 2 horizontal stiffening plates (depending on the type of standard portal structure), that are installed between the 2 diagonal knee-brace angles to help stiffen them. See further below for more details on the portal knee-brace impediments.

Note:

As sophisticated as the CCalc program was back then, it *did not perform any strength calculations of OHW loading on the cantilevers or their support structures*. Instead, the cantilevers were mechanically tested for typical worst-case loadings, and any cases of abnormally high loadings were to be checked out by Civil Design on a case-by-case basis.

To include strength checks would have made the already large program too large for the computer system to cope with at the time of writing it (1985). The main culprit back then was computer memory, and the CCalc program already had to implement ways to minimise program memory usage.

In any case, strength checks were not in the scope during development of the program – it was "simply" meant to be a way of calculating the parts and their geometry, to allow cantilevers to be accurately and conveniently built.

Because one end of the "guitar head" fitting (used in a number of cantilever *Types*) fits firmly into the cantilever pipe, any change in pipe angle away from its designed 30° position will result in various vertical offsets, as demonstrated in *Figure 228*. The pipe angle comes from the selection of *standard pipe lengths* in 125mm increments, and it can cause small offset "errors" to occur – 30mm and 14mm shown here for the supposed minimum and maximum pipe angles of 23° and 45° respectively (relative to horizontal).

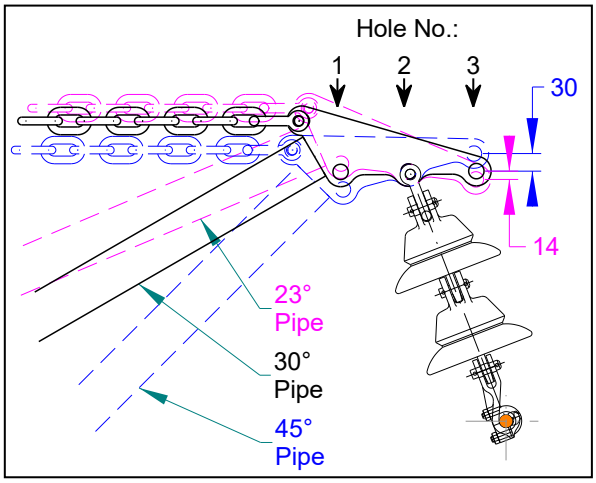
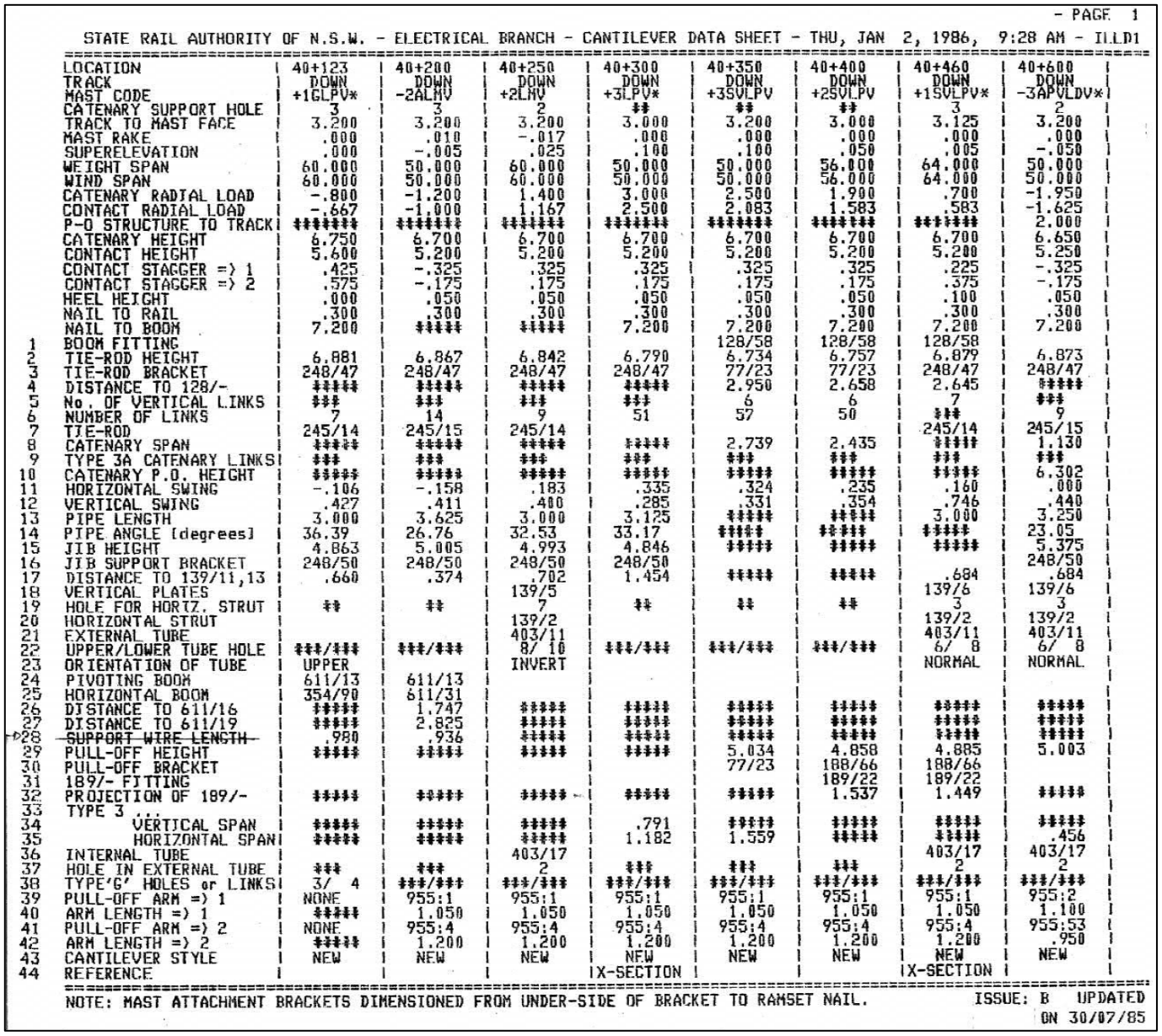


Figure 228 - Offsets Introduced by Pipe Angle

The CCalc program works these offsets out accurately when it calculates the resulting cantilever shape. [The design catenary position (height and stagger), plus the calculated insulator swing, locate the ideal position of this pivot attachment point onto the "guitar head" fitting in one of its user-selectable 3 holes.]



- PAGE 1

STATE RAIL AUTHORITY OF N.S.W. - ELECTRICAL BRANCH - CANTILEVER DATA SHEET - THU, JAN 2, 1986, 9:28 AM - ILLD1

	LOCATION	40+123	40+200	40+250	40+300	40+350	40+400	40+460	40+600
	TRACK	DOWN	DOWN	DOWN	DOWN	DOWN	DOWN	DOWN	DOWN
	MAST CODE	+1GLPV*	-2ALMV	+2LMV	+3LPV*	+3SVLPV	+2SVLPV	+1SVLPV*	-3APVLDV*
	CATENARY SUPPORT HOLE	3	3	2	##	##	##	3	2
	TRACK TO MAST FACE	3.200	3.200	3.200	3.000	3.200	3.000	3.125	3.200
	MAST RAKE	.000	.010	-.017	.000	.000	.000	.000	.000
	SUPERELEVATION	.000	-.005	.025	.100	.100	.050	.005	-.050
	WEIGHT SPAN	60.000	50.000	60.000	50.000	50.000	56.000	64.000	50.000
	WIND SPAN	60.000	50.000	60.000	50.000	50.000	56.000	64.000	50.000
	CATENARY RADIAL LOAD	-.800	-1.200	1.400	3.000	2.500	1.900	.700	-1.950
	CONTACT RADIAL LOAD	-.667	-1.000	1.167	2.500	2.083	1.583	.583	-1.625
	P-O STRUCTURE TO TRACK	#######	#######	#######	#######	#######	#######	#######	2.000
	CATENARY HEIGHT	6.750	6.700	6.700	6.700	6.700	6.700	6.700	6.650
	CONTACT HEIGHT	5.600	5.200	5.200	5.200	5.200	5.200	5.200	5.250
	CONTACT STAGGER => 1	.425	-.325	.325	.325	.325	.325	.225	-.325
	CONTACT STAGGER => 2	.575	-.175	.175	.175	.175	.175	.375	-.175
	HEEL HEIGHT	.000	.050	.050	.050	.050	.050	.100	.050
	NAIL TO RAIL	.300	.300	.300	.300	.300	.300	.300	.300
	NAIL TO BOOM	7.200	#####	#####	7.200	7.200	7.200	7.200	7.200
1	BOOM FITTING					128/58	128/58	128/58	
2	TIE-ROD HEIGHT	6.881	6.867	6.842	6.790	6.734	6.757	6.879	6.873
3	TIE-ROD BRACKET	248/47	248/47	248/47	248/47	77/23	77/23	248/47	248/47
4	DISTANCE TO 128/-	#####	#####	#####	#####	2.950	2.658	2.645	#####
5	No. OF VERTICAL LINKS	###	###	###	###	6	6	7	###
6	NUMBER OF LINKS	7	14	9	51	57	50	###	9
7	TIE-ROD	245/14	245/15	245/14				245/14	245/15
8	CATENARY SPAN	#####	#####	#####	#####	2.739	2.435	#####	1.130
9	TYPE 3A CATENARY LINKS	###	###	###	###	###	###	###	###
10	CATENARY P.O. HEIGHT	#####	#####	#####	#####	#####	#####	#####	6.302
11	HORIZONTAL SWING	-.106	-.158	.183	.335	.324	.235	.160	.000
12	VERTICAL SWING	.427	.411	.400	.285	.331	.354	.746	.440
13	PIPE LENGTH	3.000	3.625	3.000	3.125	#####	#####	3.000	3.250
14	PIPE ANGLE [degrees]	36.39	26.76	32.53	33.17	#####	#####	#####	23.05
15	JIB HEIGHT	4.863	5.005	4.993	4.846	#####	#####	#####	5.375
16	JIB SUPPORT BRACKET	248/50	248/50	248/50	248/50				248/50
17	DISTANCE TO 139/11,13	.660	.374	.702	1.454	#####	#####	.684	.684
18	VERTICAL PLATES			139/5				139/6	139/6
19	HOLE FOR HORTZ. STRUT	##	##	7	##	##	##	3	3
20	HORIZONTAL STRUT			139/2				139/2	139/2
21	EXTERNAL TUBE			403/11				403/11	403/11
22	UPPER/LOWER TUBE HOLE	###/###	###/###	8/ 10	###/###	###/###	###/###	6/ 8	6/ 8
23	ORIENTATION OF TUBE	UPPER		INVERT				NORMAL	NORMAL
24	PIVOTING BOOM	611/13	611/13						
25	HORIZONTAL BOOM	354/90	611/31						
26	DISTANCE TO 611/16	#####	1.747	#####	#####	#####	#####	#####	#####
27	DISTANCE TO 611/19	#####	2.825	#####	#####	#####	#####	#####	#####
28	~~SUPPORT WIRE LENGTH~~	.980	.936	#####	#####	#####	#####	#####	#####
29	PULL-OFF HEIGHT	#####	#####	#####	#####	5.034	4.858	4.885	5.003
30	PULL-OFF BRACKET					77/23	188/66	188/66	
31	189/- FITTING						189/22	189/22	
32	PROJECTION OF 189/-	#####	#####	#####	#####	#####	1.537	1.449	#####
33	TYPE 3 ...								
34	VERTICAL SPAN	#####	#####	#####	.791	#####	#####	#####	#####
35	HORIZONTAL SPAN	#####	#####	#####	1.182	1.559	#####	#####	.456
36	INTERNAL TUBE			403/17				403/17	403/17
37	HOLE IN EXTERNAL TUBE	###	###	2	###	###	###	2	2
38	TYPE'G' HOLES or LINKS	3/ 4	###/###	###/###	###/###	###/###	###/###	###/###	###/###
39	PULL-OFF ARM => 1	NONE	955:1	955:1	955:1	955:1	955:1	955:1	955:2
40	ARM LENGTH => 1	#####	1.050	1.050	1.050	1.050	1.050	1.050	1.100
41	PULL-OFF ARM => 2	NONE	955:4	955:4	955:4	955:4	955:4	955:4	955:53
42	ARM LENGTH => 2	#####	1.200	1.200	1.200	1.200	1.200	1.200	.950
43	CANTILEVER STYLE	NEW	NEW	NEW	NEW	NEW	NEW	NEW	NEW
44	REFERENCE				X-SECTION			X-SECTION	

NOTE: MAST ATTACHMENT BRACKETS DIMENSIONED FROM UNDER-SIDE OF BRACKET TO RAMSET NAIL. ISSUE: B UPDATED ON 30/07/85

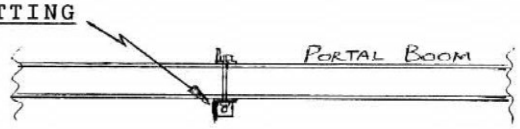
Figure 229 - Typical CCalc output

The CCalc program has been kept up to date over the ensuing years, to remain relevant as new standard fittings were added and others removed, and standard arrangements improved to what they were before I left the organisation in 2014.

In the end, the time spent developing this program was well worth it, as CCalc is still in use today (some 35 years later), and is still offering accurate and detailed construction information. Refer to *Figure 658* (the green lines), for an idea of how much of the electrified network is now regulated (or was in 2011), and probably more than 60% of that would be supported by the Mark-2 cantilevers.

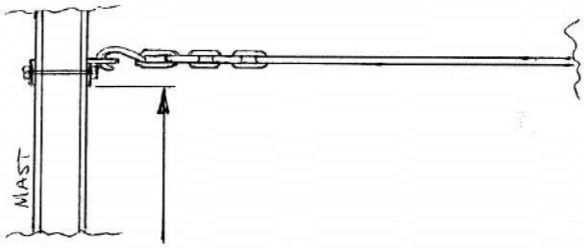
For design details of the Mark-2 cantilever and the CCalc Computer Program that generates construction details for these arrangements, refer to "CCalc – Program for Calculating Mark-2 Overhead Wiring Cantilevers on the HP3000 Computer", dated 14/2/1986.

(1) BOOM FITTING



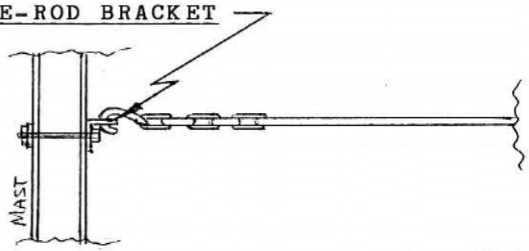
This displays the particular 128/- fitting to be used as the portal boom attachment for registering the catenary suspension arrangement
- only occurs for suspension arrangements.

(2) TIE-ROD HEIGHT



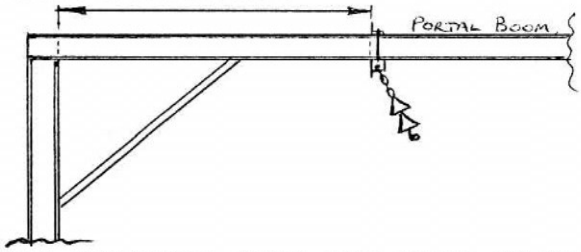
The distance from the reference NAIL to the underside of the tie-rod attachment bracket (m).

(3) TIE-ROD BRACKET



This displays the particular 248/- (or 77/-) fitting to be used as the tie-rod bracket (or suspension span bracket)

(4) DISTANCE TO 128/-



The distance from the face of the portal leg or face of dropper along the portal boom to the closest part of the 128/- fitting (depending on whether cantilever is on a portal leg or dropper respectively) (m)

Figure 230 - Interpretation of some CCalc Output (extract from Users Manual)

The "CCon" Program

Another program called "CCon" (short for CCalc Construction) was written by some consulting firm for Sydney's OHW Construction group at Strathfield in the late 1980s.

This program was intended to help interpret the CCalc output and provide stick diagrams for each location. It included other nice things such as the dropper details for each bay and the

QA sheets to be completed for handover to the client (District) at the end of the construction, before allowing trains to run.

Unfortunately, this program had apparently become difficult to keep going (which, I was told, had something to do with compatibility problems with ever faster PCs?).

CCalc Interference Checks

When the CCalc program was written in 1985, it took into account a number of potential interference obstacles or characteristics in order to calculate cantilevers that can be reliably built. Essentially this means that, provided they are installed exactly to the details CCalc provides, they will accurately position the all-important contact height and stagger (within tolerance of the design position of track), with the least probability of needing adjustment in the field. This is provided the track is within tolerance.

Portal Knee-Brace

In the case of a knee-brace on a portal leg, the CCalc program knows the exact location of these brackets and any knee-brace battens. In this way, CCalc can generate a cantilever with its pipe missing any knee-brace mid-batten/s (1 batten, or 2 battens for double channel portals).

Of course, it will also avoid clashing the jib support bracket with the knee-brace lower end connection to the portal leg.

CCalc allowed a cantilever pipe to be located clear of these obstacles, resulting in no clash surprises in the field during construction. Refer to *Figure 316* further on for what this issue looks like. A pipe could even be placed between 2 battens if that was calculated by CCalc to be possible.

But … be aware that *the pipe clearance validity on the resulting cantilever depends on the knee-braces (length of struts and position of battens, etc.) having the same geometry as was originally designed in the mid-1980s* – otherwise, how else is CCalc supposed to know the precise location of these obstructions?

The same check applies to the tie-rod and chain, to avoid the mid-batten/s (or advising if this is not possible, so the user can change the design in some way to overcome this clash).

In the case of the various Suspension arrangements (Types 1S, 2S, etc.), CCalc checks the location of the catenary support bracket installed on the portal bridge for a clash with the top end connection of the knee-brace to the portal bridge.

Back-to-Back Cantilevers

Sometimes a cantilever's proposed mast attachment brackets might interfere with other brackets already installed on a mast or drop vertical, such as in a back-to-back cantilever situation.

This potential conflict should be anticipated by the designer, and a solution provided to allow construction staff to build the cantilever without delays in the field.

The cantilever's triangular frame itself can be adjusted in a few ways, as described below. But there may be other types of clashes that need to be worked out, and this may necessitate a cross-section drawing to be developed to show the proposed solution for construction.

Cantilever Frame Adjustments

To help provide some control over the cantilever frame, mostly in order to overcome various types of problems, CCalc can let the designer set the following 3 attributes of the cantilever frame itself when it's calculated:

- ***Automatic Mode***, or
- ***1. Pipe Length***, or
- ***2. Pipe Angle*** (to horizon) or
- ***3. Jib Support Bracket Height***.

These variables are depicted in *Figure 231*. Changing any one of these 3 variables will affect the other 2.

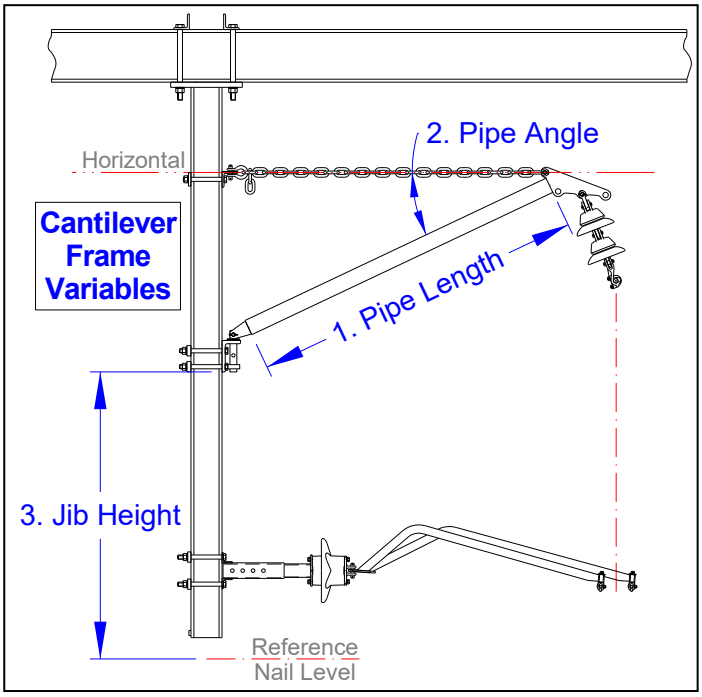


Figure 231 - Control of Cantilever frame

Note that the height of the top mast bracket for tie-rod & chain is set by the catenary height and the vertical component of insulator swing, as well as the need for the chain to be horizontal. So, this bracket cannot be included in any adjustments here. (Actually, any change in the pipe angle will alter the rotation of the "guitar head" fitting and thus affect vertical offsets, but CCALC works this out and makes the necessary adjustments for an accurate result).

It might be that a set length of pipe is needed, or to avoid a bracket on the mast that's near the jib support bracket, or just setting a shallow pipe angle.

The program will display any subsequent warnings of problems that might arise from setting one of the variables, for the designer to (re)consider.

There is an initial option, that is "Automatic Mode", to make CCalc calculate a fresh cantilever and display the 3 variables, as it would have done initially (although you'd probably start with this to get a feel of what CCalc would have provided anyway, then vary as needed from this configuration).

It stays in a loop, allowing the operator to try several of the above options (with feedback) until satisfied with the outcome, before proceeding to the next cantilever in the wire run.

Signs of Improperly Installed Mk-2 Cantilevers

There are a few basic *tell-tale signs* that a cantilever has been installed contrary to the CCalc computer program output. This is important as the CCalc program designs each cantilever accurately, so the below tell-tale signs can give an immediate indication that something is not right with the construction of that cantilever (although it could also be due to design error or because of an unforeseen impediment in the field when building it).

So, if the catenary and/or contact wire stagger or heights aren't within tolerance of the design position of track (or reference nail in mast), then it would be wise to check the various cantilever setup distances against CCalc output.

Top Chain not horizontal

→ ***All Cantilevers***

If the length of chain at the top of the cantilever is other than horizontal, this indicates that either the height to the underside of tie-rod support bracket or jib support bracket, or the length of chain (number of links) or pipe length is incorrect – or it could be due to a combination of these 4 aspects.

The shape of the cantilever triangle is quite sensitive to any one of the above aspects being wrongly installed, and it most likely shows up as a non-horizontal top chain.

Yes, you can cheat and adjust something so that the top chain is again horizontal, but the proper thing to do is to check heights and distances against what CCalc shows, as this information is quite accurate.

I note that sometimes the non-level chain might be caused by interference with existing brackets on the support mast. This can come about with back-to-back cantilevers (sometimes installing Lindapter cleats can help here), or with a non-standard knee-brace bottom connection to portal leg (CCalc cannot know the position of any non-standard bracket), etc.

Vertical Platform not vertical

→ ***Type 1, 2 Cantilever on Mast or Portal Leg***

This would result in the telescoping tubes out to the post type insulator not being horizontal. This in turn affects the heel height.

(*Note:* the CCalc program deliberately leans the Vertical Platform back by 1° from vertical, to help compensate for take-up in the holes when the 2 attachment bolts are installed and tightened, in order to provide a telescoping tube arrangement that is closer to horizontal.)

Horizontal Boom not horizontal

→ ***Type 1A, 2A Cantilever***

This can result from the pivot attachment bracket to pipe (jib) not installed at the correct diagonal distance up from the bottom end of the pipe. Alternatively (or in addition), the "V" attachment wires from catenary to horizontal boom may not be set correctly.

The heel height can suffer in this case. If severe enough, it can also sometimes cause stability problems with extremely high contact radial loads transferred into the boom.

Direct Span Connection to Cantilever Pipe

→ ***Type 3 Cantilever***

There have been a number of instances where the large Type 3 contact radial load has been transferred directly back to the cantilever pipe. No standard arrangement shows such a configuration!

The load is meant to be transferred back to the mast (via jib pin or mast attachment bracket), and a vertical chain is attached to the pipe for the purpose of setting the pull-off arm heel height (which then only places a small load on the pipe).

A direct connection of horizontal span to the pipe acts to deliberately buckle the pipe (which is already under a large compressive load). The greatest buckling effect occurs if the connection is made half way along the pipe. Note that any corrosion within the pipe can weaken the pipe and accelerate this buckling process.

If the pipe buckles, the cantilever will collapse and bring down the adjacent bays of OHW conductors.

Twin Catenary

Developing twin catenary / twin contact OHW systems was seen as a way of increasing the current rating of the OHW, and primarily in order to avoid having an auxiliary feeder run in parallel with the OHW (with its inherent risks).

The easiest way of including the second catenary was to use a "twin connecting link" (fitting 410/15), connected to the tongue of the bottom suspension insulator, that then connected the 2 catenary suspension envelopes (spaced 150mm apart). Refer to *Figure 232*.

Figure 232 - Twin Catenary support from Cantilever

Having this catenary configuration meant having better control of the behaviour of that second wire (instead of locating the auxiliary feeder remotely and having to check its clearances, etc.) In this case there is no main catenary wire – they both take on that role.

The CCalc program accommodates the length of this extra link for the twin catenary systems.

One complication to this arrangement was that the individual catenary heights are most often different, and this difference depends on the degree of insulator swing (resulting from the interaction of catenary radial load and system weight load). Refer to *Figure 233* for what this looks like. The design catenary height is to the midway position between these 2 wires.

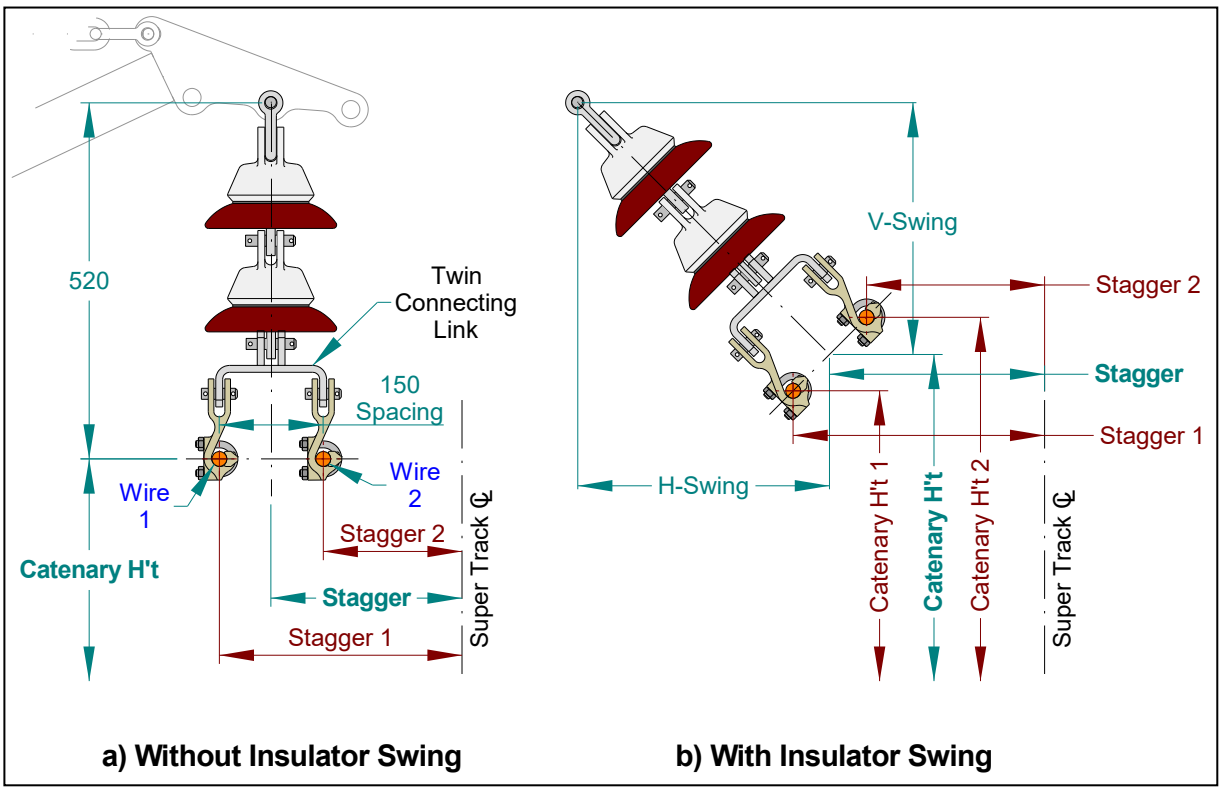


Figure 233 - Effect of Insulator Swing on Twin Catenary Heights & Staggers

For example, a design catenary height of 6.5m may actually result in individual catenary heights of 6.44 and 6.56 at a particular location, i.e. one 60mm lower and the other 60mm higher. In fact, if the insulator swing is almost horizontal, the individual heights may differ by almost 150mm (i.e. ±75mm)! To make matters even more interesting, if the insulator

swing (radial load) is in the opposite direction, then the individual catenary height values swap – in this example, they'd be 6.56m and 6.44m respectively.

This complication of determining catenary heights was left up to the CCalc program to resolve. However, it also had to be consistent with the individual catenary wires throughout the wire run, i.e. knowing whether the left-hand catenary (wire 1 with back to Sydney) was *lower* or *higher* than the right-hand catenary (wire 2) at each successive support location. This is because they can readily swap from location to location, depending on the direction of the insulator swing.

CCalc prints out these *individual catenary heights* and in their *correct order* at each successive location, so they can be fed into the dropper program. The dropper program can then determine the individual dropper lengths needed to get the correct contact profile in all bays of a wire run.

Extra care is needed when running the twin catenaries, that they do not cause any twisting of the twin connecting link which might otherwise damage the twin suspension insulators. Both wires are typically run together (see *Figure 623* much further on) and transferred on to "gin wheels" temporarily attached to the remote end of the cantilever. When the entire run is tensioned and it comes time to transfer the catenaries over to their respective suspension clamp, their relative positions need to be correctly set, before being permanently locked in the suspension clamp (with its included U-bolt fastener).

There are currently only 2 twin catenary systems, both supporting 2x137mm² contacts:

- 2x270mm² catenaries (OHW System 12), and
- 2x165mm² catenaries (OHW System 15).

Refer to *Section 4.2.4* for more details of the Mark-2 cantilevers. Refer also to *Section 4.2.5*, *Twin Catenary OHW Systems*.

3.2.1.6 Status (c. 2014)

Mark-2 cantilevers are the preferred cantilevers.

Other types of cantilevers may still be used, if appropriate, amongst existing like cantilevers. (See *Table 23*).

The Type 2A cantilever arrangement for Mark-1 cantilevers (marked ** in *Table 23*) is generally not to be used in future, because it can twist its support mast and generate alignment problems.

The Type 3A cantilever arrangement for Mark-1 cantilevers is generally not to be used in future due to the loss of independent registration caused by the contact spans passing between tracks.

3.2.1.7 Reference

Refer to *Table 20* and *Table 21* in *Section 3.2* for relevant drawings.

See *Table 23* for typical cantilever references.

For design details of the Mark-2 cantilever and the CCalc Computer Program that generates construction details for these arrangements, refer to *"*CCalc – Program for Calculating Mark-2 Overhead Wiring Cantilevers on the HP3000 Computer*"*, dated 14/2/1986.

3.2.2 Suspension Arrangements

3.2.2.1 Description

OHW suspension arrangements are typically installed on portal structures and often have span wires crossing the tracks from one portal leg to the other. They can also be found inside tunnels (with tall ceilings) and at various stations and air-space developments.

They are commonly used in fixed-anchored OHW systems, although sometimes they are incorporated into regulated OHW systems as well, but under strict conditions of limited wire movement with temperature.

3.2.2.2 Function

Portal suspension arrangements provide the following functions:

- They can position both the catenary and contact wires at a particular height and stagger relative to the design track position.
- They allow a convenient means of supporting the catenary weight, radial and wind loads and registering the contact radial and wind loads.
- They achieve the above requirements with arrangements that are relatively cheap to build and easy to install and maintain. This is particularly relevant for multi-track situations. However, this likely comes at the cost of loss of "Independent Registration".

Figure 234 - Fixed-Anchored Suspension arrangements on Portal structure (Hornsby)

3.2.2.3 Typical Components

Refer to *Figure 236* for most of the components of a typical situation.

These arrangements almost always include the following major components:

- Suspension insulators, for connecting the catenary wire to the underside of portal bridge.
- Suspension brackets, which connect these insulators to the portal bridge, sometimes with a vertical steel rod to lower the catenary to the correct height. These brackets allow simple lateral adjustment to the get the correct catenary stagger.
- Catenary suspension envelope (clamp) for connecting the catenary to its suspension insulators.
- A catenary steady span, made from stranded copper or steel wire (or more recently using a suitable length of chain). This helps to achieve an accurate stagger for each catenary wire.
- A pair of side-strain insulators on one or both legs of the portal, connecting the pull-off steady span (cross-span) which is stranded hard-drawn copper wire. A mid-track insulator may also be incorporated into this cross-span arrangement for electrical sectioning purposes.

- A short length of span wire, to attach to the cross-span for connecting a pull-off arm.
- Pull-off arm/s registering the various contact wires.
- Contact clamp/s, which connect each arm to its contact wire.
- A "fender" may be installed at a pull-off arm, with 2 clips attaching it to the contact wire and located under the span wire. This is sometimes needed to prevent excessive contact wire uplift, especially under fixed-anchored hot conditions (low tension) and/or with the closely spaced multiple-pantographs up from an electric freight train (however they are no longer operating in Sydney). Refer to *Figure 235*.

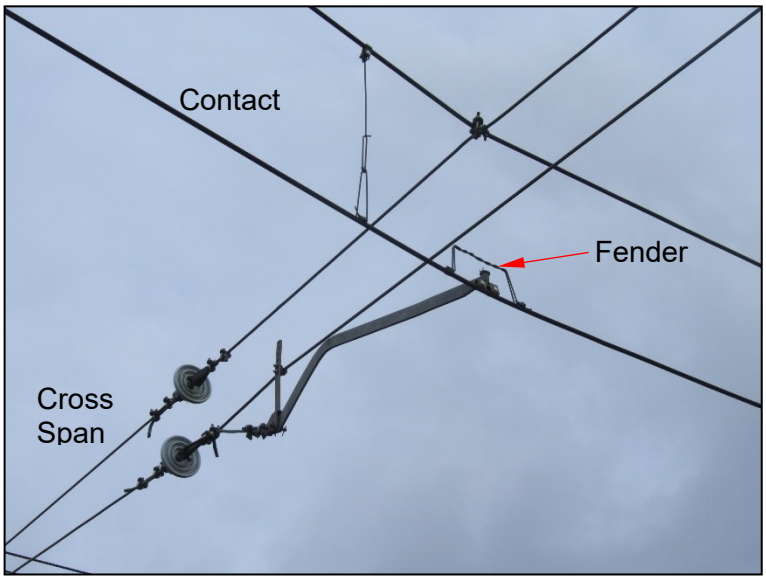


Figure 235 - Typical Fixed-Anchored Cross Span Pull-Off arrangement

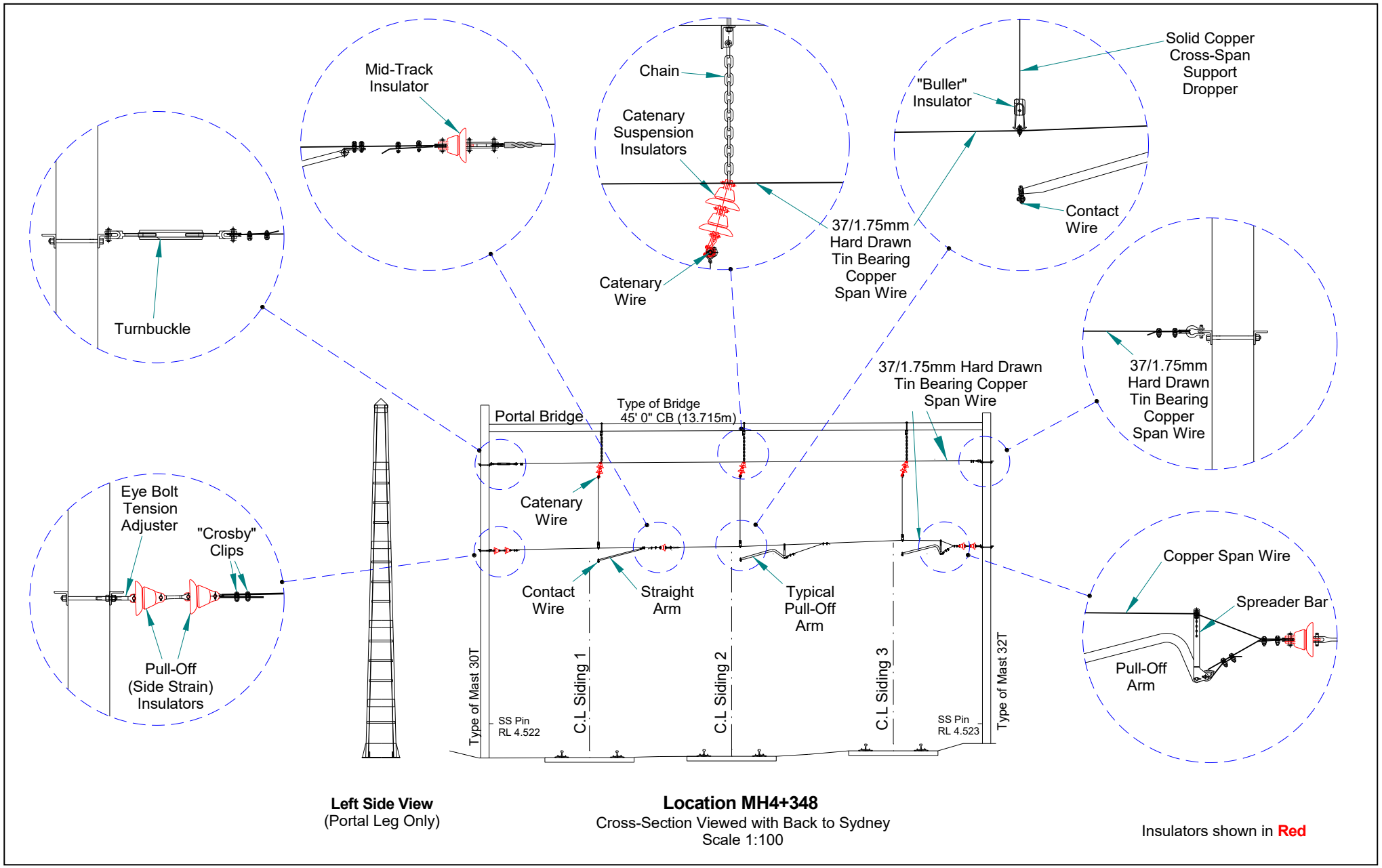


Figure 236 - Typical Suspension arrangement on Portal structure (at Lavender Bay Sidings)

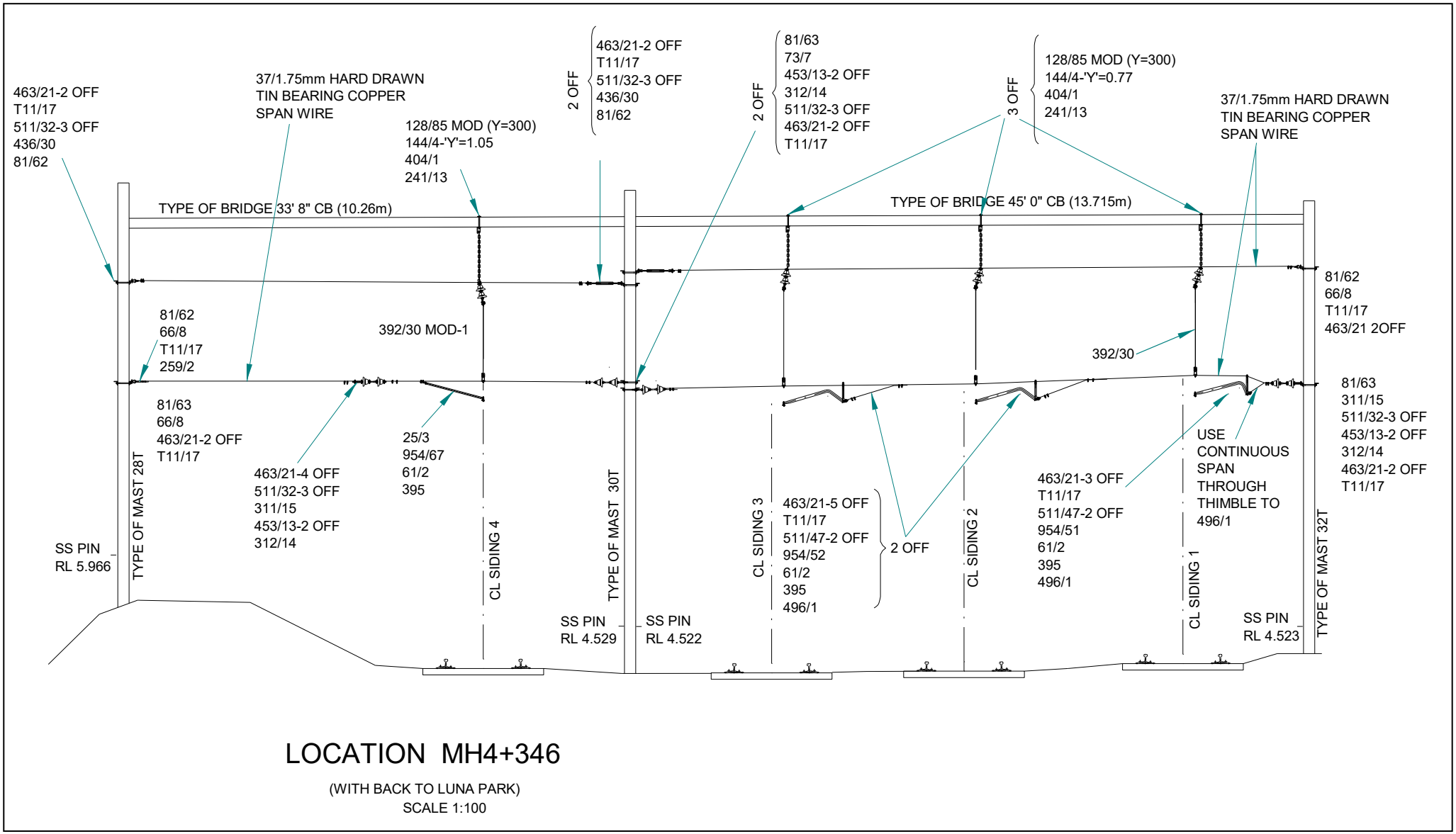


Figure 237 - Typical Multi-Track Suspension arrangement Cross-Section (showing OHW Fitting Numbers)

3.2.2.4 Configuration

The term "suspension" comes from the fact that the catenary is *suspended* from the underside of the bridge of a portal using a pair of suspension insulators (which are thus in tension). *Figure 238* shows a portal suspension arrangement in the compound OHW system. (I put this photo in also because of the magnificent Blue Mountains scenery!)

The catenary insulators are shown swung in the direction of the catenary radial load (under the influence of the considerable weight load imposed by the adjacent half-bays of OHW conductors).

Figure 238 - Compound OHW Portal Suspension in Blue Mountains

The typical standard catenary height for the old fixed-anchored OHW was 7.06m (23'-2") and contact height was 5.03m (16'-6"), giving quite a deep system depth of 2.03m. For bays longer than 73m (needing intermediate pull-off spans), the catenary height and system depth needed to be even greater (and requiring even taller portal structures).

Spans crossing the tracks are often associated with suspension arrangements, and this can unfortunately result in OHW problems on one track affecting train running on the other adjacent tracks.

Independent registration is the term used to describe an OHW configuration that has no crossing spans *between* tracks, thus avoiding the above problem. This approach is now mandatory wherever it's deemed practical (it can't be employed at crossovers, turnouts, etc.).

Portal suspension arrangements are less commonly used with regulated OHW, unless there is sufficient "swing" in the suspension arrangement to allow the catenary wire to move unimpeded in the longitudinal direction (the direction of the track) with changes in the conductor temperature. (This means being less than 100m from a fixed anchor or fixed mid-point anchor). Also, it should not change the catenary height by much in doing so – having a long insulator string length helps in this regard.

In regulated OHW, the various suspension arrangements can be generally used anywhere up

to about 100m from a fixed anchor or fixed mid-point anchor location. Beyond that, cantilevers are needed.

A *fender* is usually installed onto the contact wire in situations where a pull-off cross-span crosses above the contact swivel clamp. Refer to *Figure 239*. Fenders are protective devices, designed to push the above span wire up in the case of excessive pantograph uplift, thus reducing the likelihood of the span hitting the pantograph. In doing so, the fenders also limit the amount of contact uplift, which is a good thing. The total absence of the old multiple-header electric freight trains, with their closely-spaced pantographs, possibly means these devices are no longer needed.

An *insulated steady wire dropper* is a vertical solid copper wire which supports the pull-off cross-span from the catenary suspension point, thus reducing the likelihood of the pull-off span sagging into the path of a pantograph. The dropper itself is alive at 1500V, but incorporates a porcelain *loop strain insulator* to prevent any current feeding through the arrangement from catenary to contact hardware. Refer to *Figure 239*.

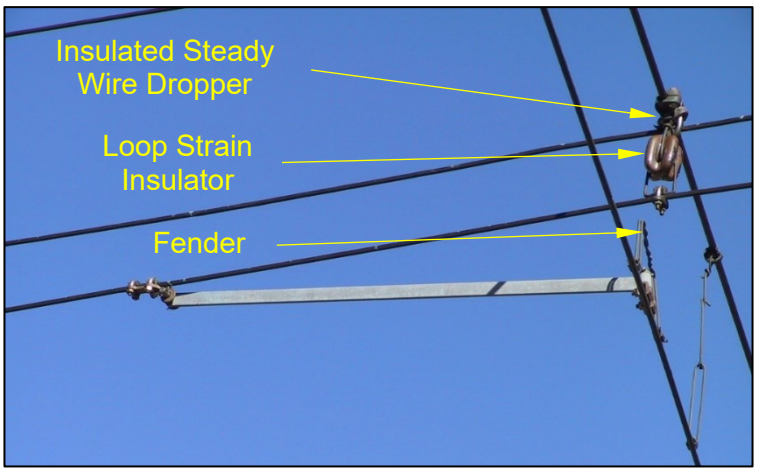


Figure 239 - Pull-Off Cross Span at the Pull-Off Arm

A *mid-track insulator* is installed in the pull-off cross-span at a location midway between the tracks to allow for electrical sectioning of the overhead wiring if needed.

CONTACT-ONLY SUPPORT

I include the *contact-only* support arrangement in this category ("portal suspension arrangements") because there is no other category, and they seem to be relevant here. Refer to *Figure 240* for an example from the Country Platform Roads at Central Station.

This arrangement is relatively simple and has proven to be quite reliable, probably as a consequence of its simplicity. However, it needs to be more frequently spaced than those of a catenary/contact system, due to rather large contact sag, and also because its fixed-anchored tension changes with temperature (although not as much as if it were supported by droppers from a catenary).

Figure 240 - Contact-Only Support arrangement (at Central, Country Platforms)

Of course the disadvantages to this arrangement are the consequent slow speed train running and fairly minimal current capacity to supply and run trains (due to the single conductor). But it

seems to work well at Central leading into the country platforms, and has done so for many decades in this situation.

More details of the contact-only OHW system are contained in *Section 4.1.8*.

3.2.2.5 Design Notes

General

Suspension arrangements are normally associated with fixed-anchored OHW. The catenary can be simply suspended through a pair of suspension insulators from the portal bridge. Likewise the contact wire can be registered from the portal leg, again using a pair of side strain insulators or single post type insulator.

However, even regulated OHW can use these arrangements in limited circumstances. Usually this means they can be installed within 100m of a fixed mid-point or fixed anchor arrangement, so that the amount of wire extension and contraction with temperature changes is limited to about ±100mm from its normal (21°C) position. In this case, any change in catenary height as the insulator swings is fairly minimal and not likely to pose an operational problem to trains as the contact wire lifts marginally.

Effects of Temperature Changes

In a fixed-anchored OHW system, if there's any catenary radial load at the suspension location, the changes in catenary tension due to temperature will cause the catenary suspension insulators to swing to a different position. Cold temperatures (increased tension) will cause the insulators to swing further towards horizontal, and hot temperatures (lower tensions) will cause less insulator swing, closer to being vertical. See *Figure 193* further back.

The change in insulator swing due to temperature needs to be accommodated in the design for each location, so as to ensure there's no operational problems at the extreme temperatures.

In terms of horizontal swing component, any change in catenary *stagger* is unlikely to cause any significant problems.

However, the change in catenary *height* can be an issue in the following situations:

- If there's an *overline bridge* located in the adjacent bay, then any increase in catenary height will lead to a reduced vertical clearance to the bridge.
- If the supported contact wire has been lowered, because of a *low bridge* or if inside a *tunnel*, then any reduced catenary height will lower the contact also, and this reduced contact height throughout the adjacent bays must remain well above the absolute minimum contact height of 4.57m.

Both above effects are normally checked out during the design process.

In the case of low contact height, if the track is installed on ballast, then the tolerance of the track needs to be taken into account as the track is a moving thing. (However, if the track has been solidly anchored to a concrete slab for instance, then it's not going to move, which can be a better outcome in these tight situations.)

Variety of Arrangements

One of the main reasons for the range of suspension arrangements is due to the need to effectively deal with the various levels of radial load.

Low radial load situations: can often lead to simple arrangements because the catenary insulator swing is small (almost vertical) and the stress on the various components is

relatively low. However, sometimes there are pull-off spans that cross all tracks to the opposite portal leg, which is needed in order to maintain a level of tension in the cross-span wire to keep it well above any passing pantographs. This full span is needed if wind blows against the light contact radial load (which could otherwise collapse the span – into the path of a pantograph).

High radial load situations: normally result in high catenary insulator swings (approaching horizontal), and increased stress on some of the span components. However, usually there's no need for a full cross-span, since the radial load is always much greater than any opposing wind load on the catenary and contact wires. So a two-thirds span arrangement (for twin tracks) is available which can cut down on equipment, especially insulators.

Figure 241 – "V Chain Suspension that was used in Mortdale to Sutherland

To avoid the need for a catenary cross-span, one area (Mortdale to Sutherland) used a "V" chain suspension arrangement as shown in *Figure 241*. Around the electrified network there are other instances with slight variations to the standard suspension arrangements, as different designers have come up with their own take on what should be installed (for whatever reason).

See also *Section 4*, *OHW Systems* for some examples of the various suspension arrangements, and especially *Section 4.1.1*, *Metropolitan Simple Catenary OHW System*.

3.2.2.6 Status (c. 2014)

Most portal suspension arrangements are being replaced with cantilever arrangements as the OHW upgrading (regulating) program proceeds.

Cross-spans between tracks are also being removed and replaced with arrangements that achieve *independent registration* (typically requiring drop verticals). The current "Mark-2" cantilever arrangements automatically achieve independent registration.

3.2.2.7 Reference

Refer to *Table 20* and *Table 21* in *Section 3.2* for relevant drawings.

3.2.3 Polygon Arrangements

3.2.3.1 Description

Polygon arrangements appear as an array of diagonal and horizontal *spans* crossing the tracks from one support structure to the opposite support structure (these structures would typically be wood poles).

The "polygon" itself is the upper-most span, which sets the catenary (and contact) heights.

3.2.3.2 Function

Polygon arrangements perform the following functions:

- They provide a means of supporting the catenary wire with its weight, radial and wind loads, and registering the contact wire with its radial and wind loads.
- They position both the catenary and the contact at a particular height and stagger.
- They achieve the above requirements with arrangements that are relatively cheap to build and quick to install, but can be difficult to maintain. The heights and staggers of the OHW conductors are very much influenced by any changes in cross-span tension or support structure movement (such as a wood pole in unstable soil slumping in the ground).

In past days, polygons were sometimes installed during emergencies if the existing OHW and structures were damaged due to a train derailment for instance. Polygons were a way of quickly putting the wire runs back in the air for train running, because they only required 2 wood poles (not steel portals which typically take many days to procure, install and set).

The down side was the level of adjustment needed to bring about the correct stagger and height of the various contact wires. If more than 2 wire runs needed to be installed, the complexity of adjusting cross-span lengths to get the right geometry for all OHW runs became increasingly more complex, even with computer programs to help out (although they did help a lot). After all, changing the position of one load point affects the entire arrangement, and can require a tricky balancing act to resolve the situation.

To this end, they are really only suitable in situations that can tolerate a large degree of error in the contact position – height and stagger. This is why, for important tracks, they are a short term (temporary) fix.

3.2.3.3 Typical Components

A simple polygon, as shown in *Figure 242*, will mainly consist of:

- 2 wood poles.
- Steel cross span wires (2 de-energized spans for supporting the catenary wires, and 1 for the contact wire which is alive at 1500V).
- Turnbuckles for adjusting the tensions in the various cross-spans, especially the upper polygon itself.
- Catenary suspension insulators and contact pull-off insulators.
- Pull-off arms, fenders, cross-span support droppers (to help support the cross-span).

3.2.3.4 Configuration

Referring to *Figure 242* and *Figure 243*, a typical polygon arrangement consists of the *catenary polygon span*, the *catenary steady span* and the *contact pull-off span*.

CATENARY POLYGON SPAN

This top diagonal span configuration is the actual "polygon". It supports the weight loads of the various attached OHW conductors (catenary, contact, droppers, in-span feeders, etc.).

At every catenary attachment location, its vertical load point causes the span to change direction – the amount of change depends on the weight loads of the OHW, the distance between load points and the horizontal tension in this span. (Note that any radial loads are handled by the horizontal cross-spans below.)

Unfortunately, changing the horizontal tension in this span can alter the deflection of both support structures, which in turn can alter the geometry of the polygon. This can make it an extremely awkward arrangement when needing to accurately set catenary (and therefore contact) heights.

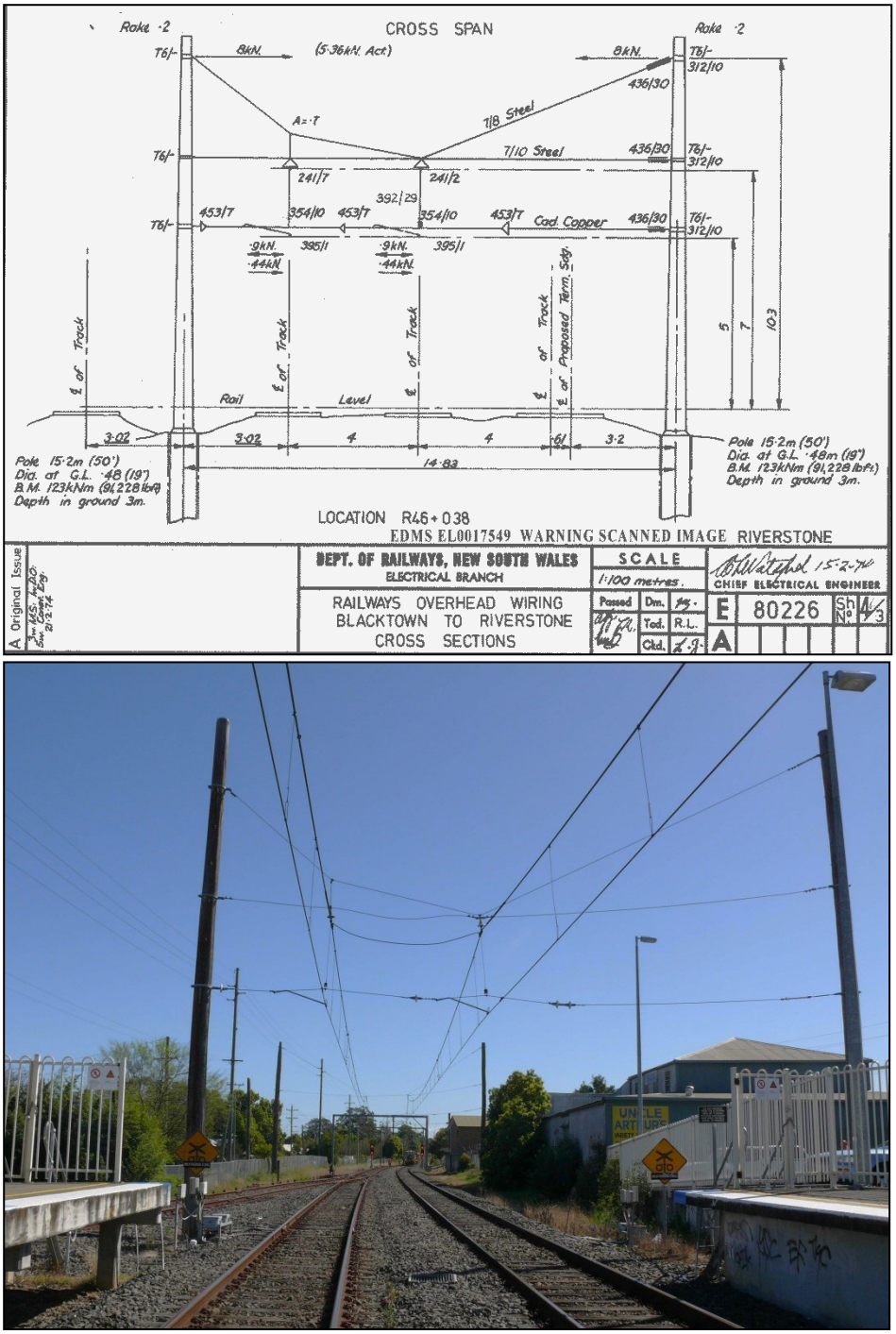


Figure 242 - Typical Polygon (design Cross-Section & actual)

A "Polygon" computer program is available to help work out the span details of the polygon arrangement, for support point loads from 1 to 5 (i.e. up to 5 runs of OHW supported by the polygon). The diagonals of the top polygon span are the focus of the program, as they're the most difficult thing to work out by manual means. However, the calculation is not that difficult (using bending moments), but it does depend on the horizontal tension in this span remaining constant from one pole to the other (in equilibrium) whilst supporting the various catenary weights acting as vertical point loads.

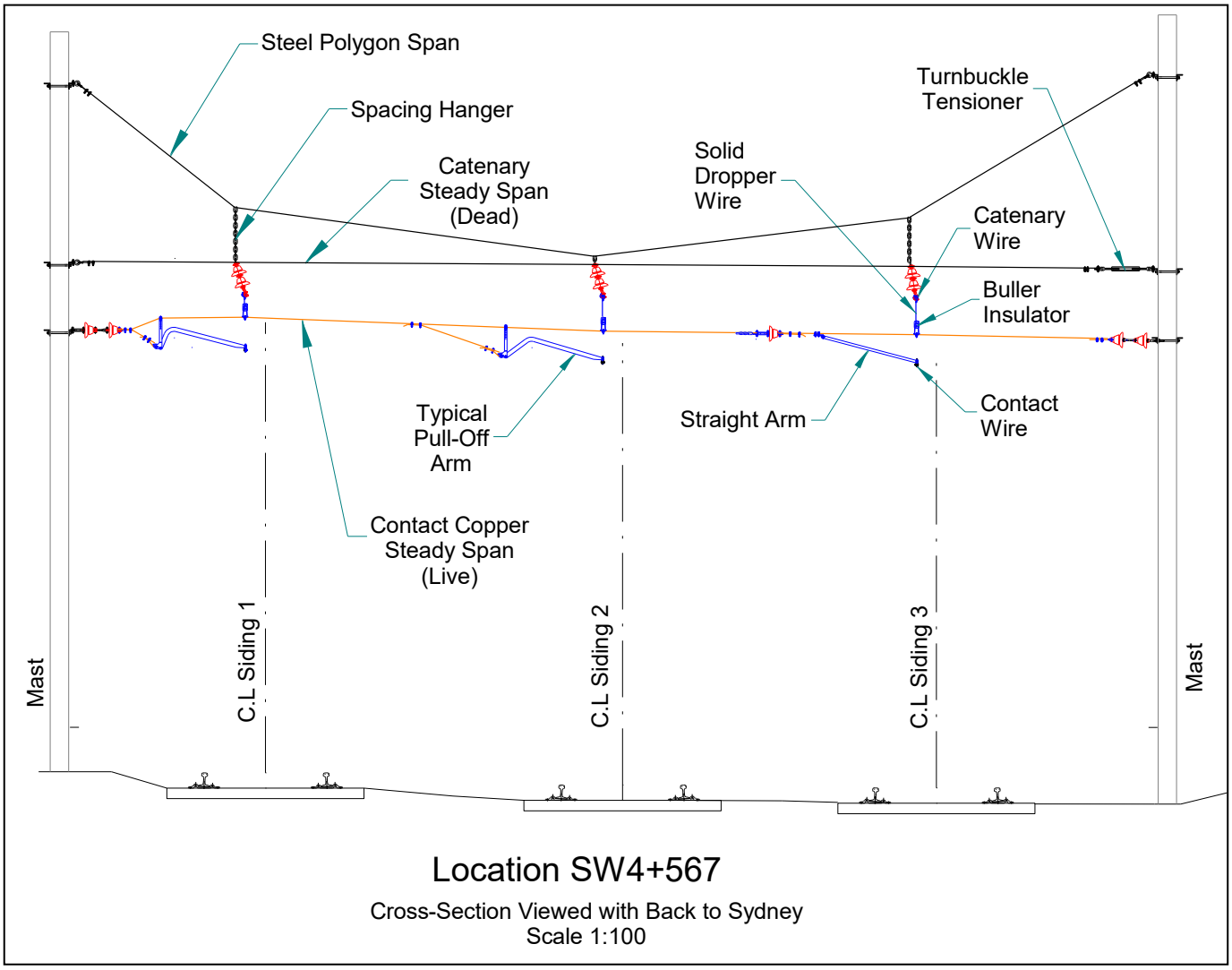


Figure 243 - Components of a Polygon arrangement

CATENARY STEADY SPAN

This span is located below the polygon span (above) and stretches across horizontally from one support structure to the other, attaching to the upper part of each set of catenary suspension insulators on the way.

This span is intended to register the (horizontal) catenary radial load through the top of the swung catenary suspension insulators. In this way, the upper polygon span only has to cope with the (vertical) weight of the OHW conductors. This makes calculation of the polygon spans much simpler. The suspension insulators in this configuration are able to swing unimpeded with the catenary radial load, and this swing needs to be taken into account to position the catenary correctly (this is handled by the computer program).

Any change in tension in this cross-span will alter the amount of deflection on both structures, which will impact the geometry of the polygon span and ultimately affect the catenary heights and as a consequence contact heights also. Therefore, great care must be exercised to not over-tension this span wire and upset the geometry of what's trying to be achieved.

CONTACT STEADY SPAN

This is the lowest span, and it crosses all tracks from one support structure to the other. This span is intended to register the contact wires through appropriately located pull-off arms, to correctly position their stagger and to hold the contact radial (and wind) loads.

Polygon arrangements usually incorporate similar cross-span arrangements to portal suspension arrangements, e.g. pull-off cross-spans, fenders, mid-track insulators, insulated steady wire droppers, etc.

As with both the catenary spans above, any change in the tension of this steady span can lead to a change the various catenary and contact heights.

It should be obvious that any significant wind loading on both structures and all attached bays of OHW conductors, can cause changes to the heights and staggers in this arrangement.

The polygon really is a simple arrangement, but in this regard there needs to be quite a latitude of tolerance with the resulting contact heights and staggers.

3.2.3.5 Design Notes

Polygons used to be a vital arrangement, for keeping costs down in relatively slow speed areas (such as shunting yards), and especially useful for train derailment situations and other emergencies that affect train operations on main lines.

They can be installed relatively quickly (using spare wood poles if needed and other common OHW hardware), in order to get trains going again, which then gives time for planning a more permanent solution to be designed and installed much later.

Unfortunately, the all-important contact heights can be susceptible to temperature changes if the OHW is fixed-anchored, but provided there's plenty of contact height, and train speeds aren't too great, then this is not so much of an issue.

The contact staggers don't change much since they're held by a horizontal steady span. However, they can be somewhat influenced by wind loading. Obviously, the stronger the wood poles the better, with less deflection and more importantly less *change in deflection* with wind loading.

The lengths of the various diagonal catenary suspension wires of a polygon can be calculated using *bending moments*, which relies on setting an appropriate horizontal tension from one pole (or mast) to the other pole (mast). This tension needs to remain relatively constant.

Whilst a polygon is a simple arrangement, it is extremely awkward to configure correctly to get the required catenary and contact wire heights (within their nominated tolerances). The more wire runs supported by the polygon, the harder it is to adjust for correct wire positions, with any altered weight loading in one wire affecting the position of the others on the polygon. And changes in span tensions can affect the pole (or mast) deflections, which can change the polygon geometry as well.

3.2.3.6 Status (c. 2014)

Polygons are now only installed:

- In emergencies (where fallen OHW support structures are to be quickly replaced so that the OHW conductors can be reinstated for train operations to resume).
- Where traffic disruption is less important and the existing OHW is supported using polygon arrangements.

3.2.3.7 Reference

Refer to *Table 20* and *Table 21* in *Section 3.2* for relevant drawings.

A typical polygon arrangement is shown in drawing E/18010 sheet 82.

A *polygon* computer program exists to determine the setup for supporting up to 5 OHW runs.

3.2.4 Pull-off Arrangements

3.2.4.1 Description

Pull-off arrangements appear as simple spans, pull-off arms and associated hardware, that hold the catenary and contact wires at a particular staggered position above a track.

They occur somewhere *within* a bay, and are configured to only *register the radial and wind loads*. They are typically designed such that they do not support any significant weight of the OHW catenary wire, and so they are unlikely to distort the catenary sag parabola in the bay.

Because the pull-off is located somewhere *within* the bay, the catenary and contact heights need to be calculated and provided by design for each pull-off location.

Sometimes there may be 1, 2 or even 3 pull-offs within a particular bay. (Multiple pull-offs were commonly employed in fixed-anchored OHW to help maximise the bay length and so minimise the amount of tension change with temperature.)

The far majority of pull-offs hold the wires with a positive radial load (i.e. loads acting away from the mast towards the track). In rarer cases, these arrangements can register negative radial loads (towards the mast), making them "push-offs", but these are less desirable and may not always be suitable.

Note:

Pull-off arrangements are generally not used in regulated OHW anymore.

3.2.4.2 Function

Pull-off arrangements provide the following functions:

- They position the catenary and/or the contact wires at a particular stagger.
- They provide a means of registering the catenary and/or contact radial and wind loads.
- For regulated OHW, they provide a means of allowing the OHW conductors to move longitudinally with temperature changes (and without affecting the stagger too much).
- For fixed-anchored OHW, they can allow extremely long bay lengths (73m) to exist (especially around tightly curved track), without compromising pantograph security. The long bay lengths are desirable as they help yield a large virtual span which, in turn, reduces the amount of catenary tension change between hot and cold temperatures. This in turn provides less change in contact height within the bay, providing a better pantograph interface.

The catenary wire in this type of arrangement is not supported, i.e. the shape of the sagging catenary profile in a bay from support to support should be unaffected by a pull-off.

As mentioned above, pull-off arrangements were used extensively in runs of fixed-anchored OHW, fundamentally as a means of keeping the bay lengths as long as practical, but also ensuring pantograph security throughout the bay.

Aside:

The conductor tension change due to temperature change is affected by its *virtual span* – see *Section 3.1.0.5*, *Virtual Span* for more information.

With a change in temperature, the corresponding conductor tension change in a conductor with a long virtual span is much less, compared to that for a short virtual span. So, it is advantageous to keep the bay lengths (from OHW support to support) as long as practical (e.g. 73m), as this results in a long virtual span and a better outcome.

It also leads to a reasonably economical design, as cheaper pull-offs can be employed within bays to ensure pantograph security (with 1, 2 or even 3 pull-offs in a bay). Pull-offs have a reduced component count and require less maintenance effort than most other types of support & registration arrangements.

3.2.4.3 Typical Components

The main pull-off components include:

- Side-strain or post type insulators installed on a mast, drop vertical or pole.
- Copper span wire and associated thimbles, crosbies (wire clips), etc.
- Chain.
- Steel channel "posts" (for holding a post type insulator at a distance from the attached mast).
- Catenary attachment clamp, such as the catenary saddle clamp or catenary bridge fitting.
- Pull-off arm/s and associated contact swivel clamps/s.

3.2.4.4 Configuration

Pull-offs normally consist of spans and/or horizontal insulator posts ("channel arms") connecting the catenary and/or contact wires to the support structure via insulators and associated hardware. See *Figure 244* for example, which depicts the current standard pull-off arrangements for a single catenary / twin contact OHW system.

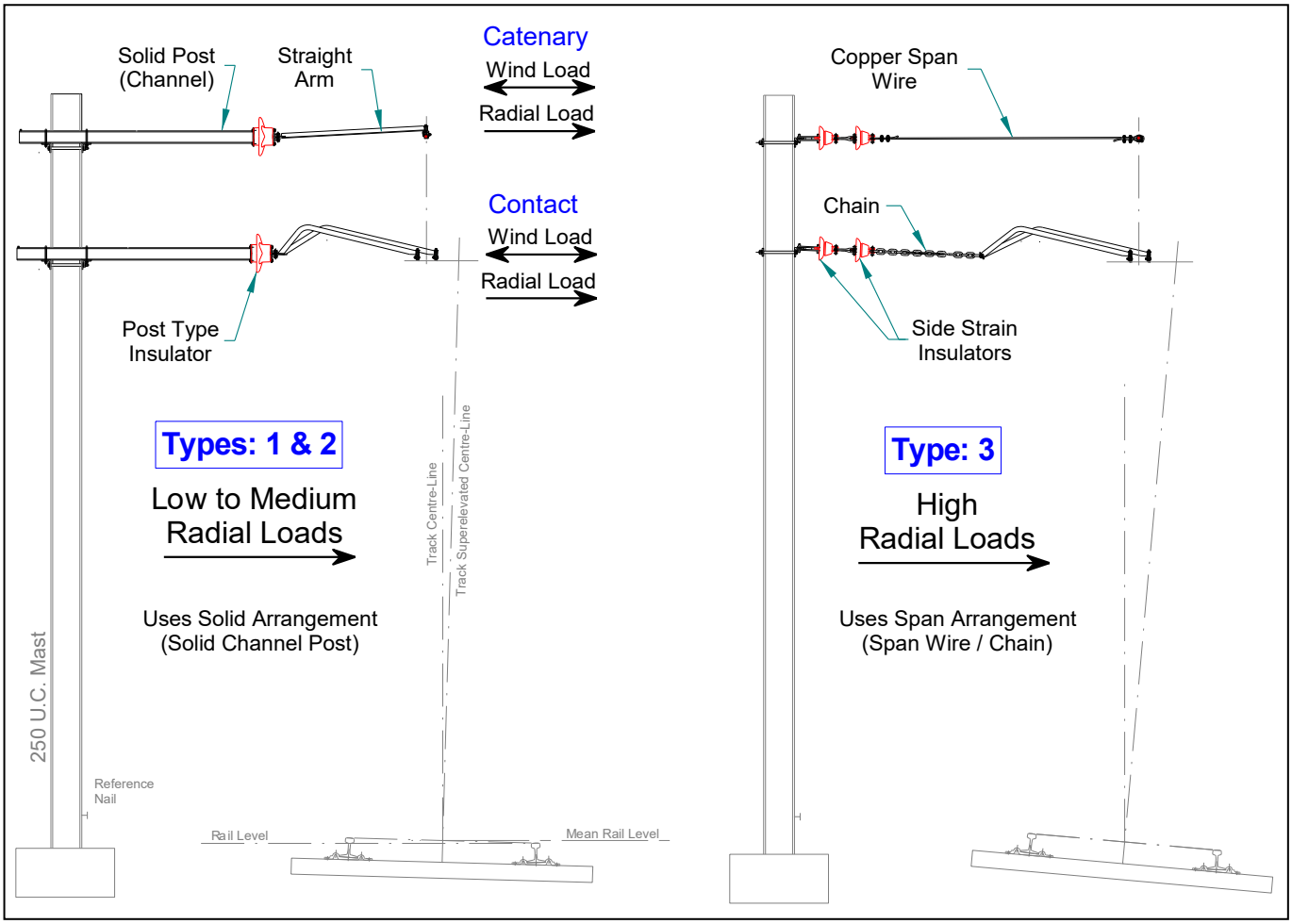


Figure 244 - Typical Regulated Pull-Off arrangements

The actual type of arrangement used at any location depends on the radial and wind loads imposed on the catenary and contact wires at that point. A low radial load is Type 1, medium load is Type 2 and higher radial loads are Type 3, as shown above. (The radial load bands are given in *Section 3.2.1.4*, *Cantilever Types*.)

Spans are preferred because they are cheap, light and easy to install and adjust. But they require a high radial load such that an opposing wind load never overcomes this radial load and thus always keeps the span taut (so that the heel of the arm doesn't slump into the path of a pantograph) – refer to *Section 5.1.23.8*, *Adverse Condition* for further details on this.

Insulator post arrangements can only handle the adjacent track (unlike spans arrangements which can span several tracks). Because of their "solid" nature, they can be used even if the wind load overcomes the radial load. So, they are intended for use with low to medium radial loads. For high radial loads, there is some uncertainty whether the post itself will slide through its deep U-bolt attachment (which partly depends on how well the nuts were secured, which can be rather subjective). Hence, high radial loads require span arrangements.

Figure 245 shows part of a design cross-section drawing for a fixed-anchored pull-off location at Lavender Bay. The project, in about 2005, was to renew all the OHW equipment except the OHW structures, to get another 5 years life while decisions were made, as I understand it, regarding the possible sale of the valuable real estate. Here, 1 track splits up into 6 tracks eventually, intended for stabling trains ready for the am and pm peak hours (which is a particularly handy / strategic location close to the centre of Sydney).

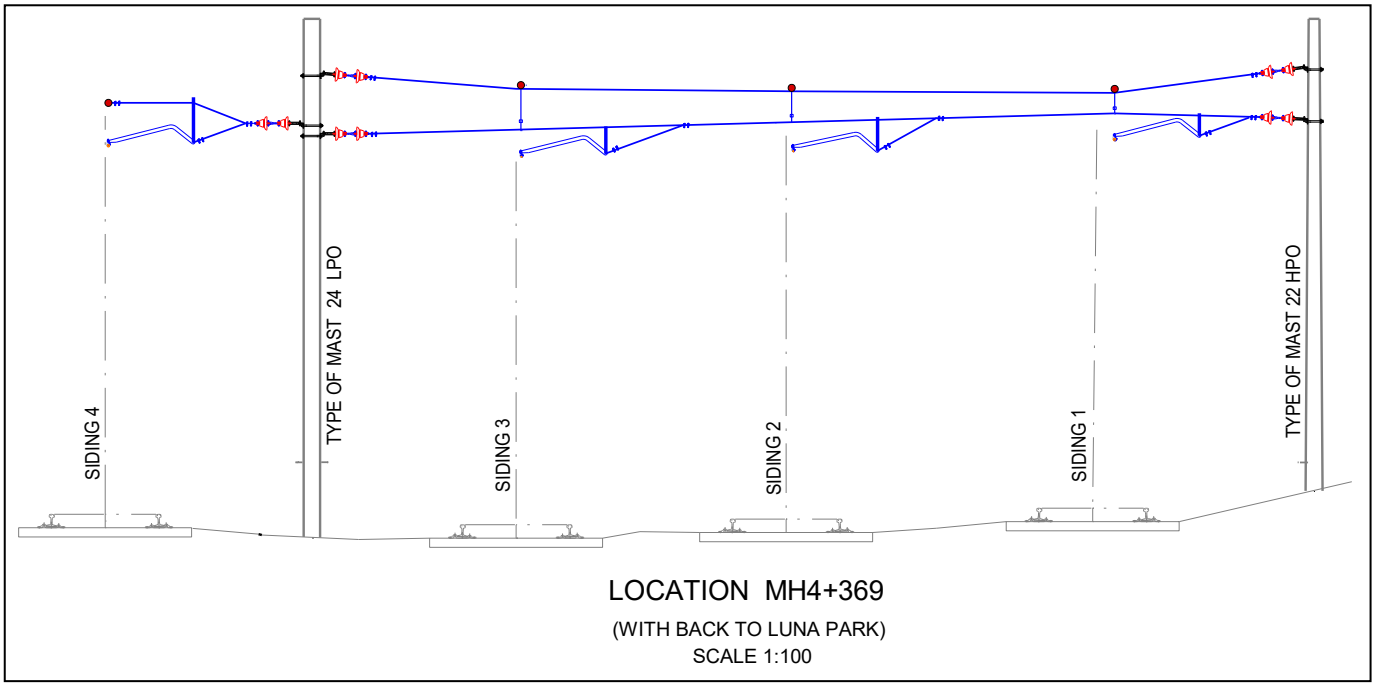


Figure 245 - Recently upgraded Fixed-Anchored Pull-Off arrangement at Lavender Bay

In this figure, cross-spans are used between the masts, with 3 attached pull-offs handling low to medium radial loads. The left-most pull-off attached to the other side of the mast registers catenary and contact wires with a high radial load.

Note the use of vertical "Spreader Bars" between cross-span and arm, to set the correct arm heel height.

The depth of the spreader bar for the left-most arrangement tries to match the system depth (catenary to contact vertical distance) at that point. In this way, the catenary height will not be affected by the connected span and its high radial load.

Also note that the 3 connected catenaries – using the common span – need to be similar heights, to avoid other complications.

Aside:

Apparently, this Lavender Bay area used to include the terminus for North Shore trains travelling southward to Sydney during construction of the Sydney Harbour Bridge in the 1930s. Refer to *Figure 246*. Ferries (near where Luna Park is currently situated) would then take people across to and from Circular Quay.

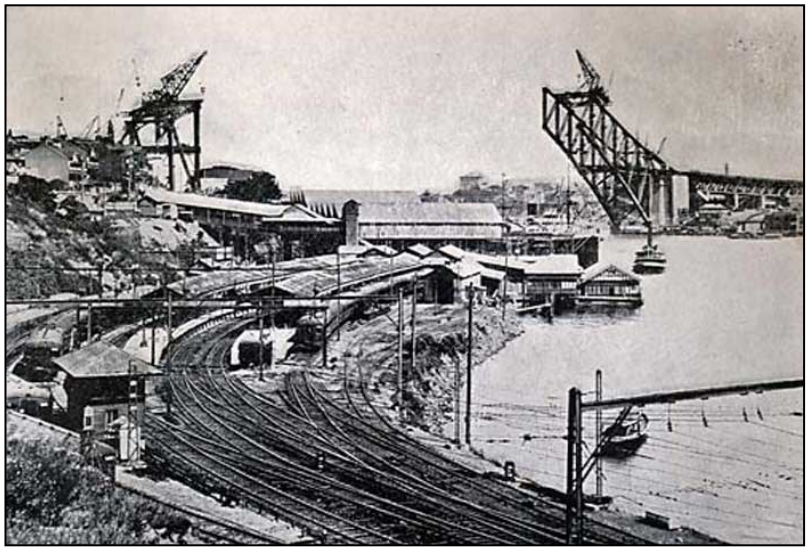


Figure 246 - OHW for old Lavender Bay Terminus

I understand there's been a recent change of plans for the Lavender Bay Car Sidings, and now the 6 stabling tracks stay, and the OHW in this area is in the process of being upgraded to a new regulated OHW system, complete with new structures – a good outcome.

The picture shows the original portal structures with suspension and mid-bay pull-off span arrangements, now in place for more than 90 years. See also *Figure 236*, *Figure 237* and *Figure 243* further back.

Figure 247 shows a pull-off using a single post type insulator and including a *raiser bracket* to attach the catenary span wire – a very economical arrangement (although its additional loading, especially the bending moment onto the post type insulator, should be checked out each time this approach is used). Again, the height of the raiser bracket tries to match the catenary height (give or take), to avoid changing the shape of the catenary parabola and thus the local catenary height. But the span must not rub against the crank in the pull-off arm.

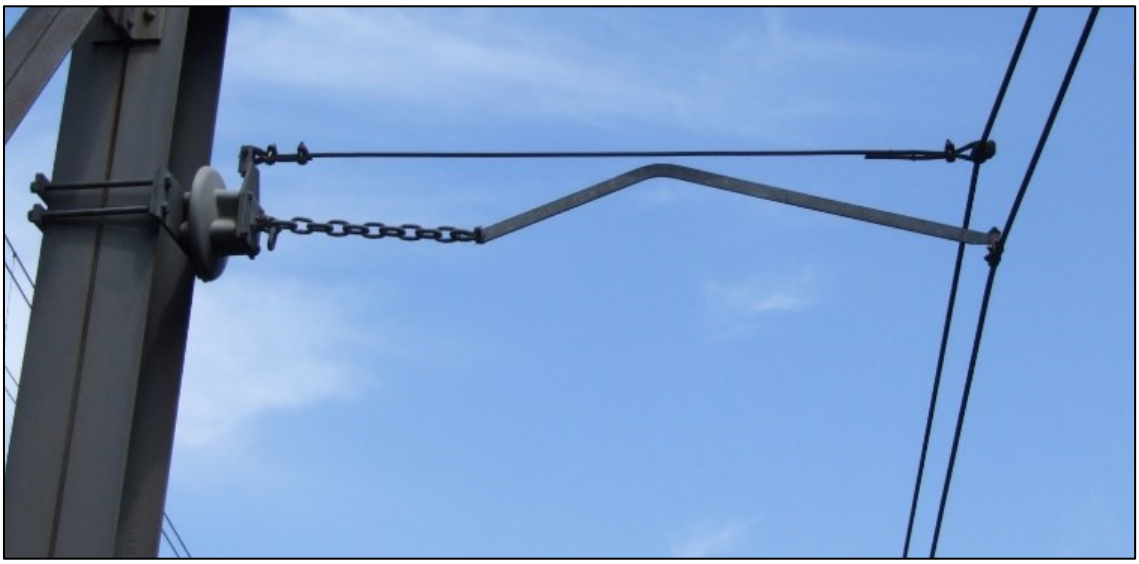


Figure 247 - Catenary Pull-Off from Raiser Bracket

3.2.4.5 Design Notes

Pull-off arrangements are all about *registration* of the OHW conductors (not their support). They are installed essentially to ensure *pantograph security* throughout a long bay.

CATENARY & CONTACT HEIGHTS

At any pull-off location, the *catenary height* is calculated knowing the heights of this wire at both adjacent catenary support points (defining the bay length), less the catenary sag to this location, and relative to the track (see below).

The *contact height* is calculated taking into account any hog or presag within the bay. Note that the height is ultimately dictated by the lengths and positions of the distributed droppers in the bay, and the way the contact wire weight is supported by these from the catenary throughout the bay. (This can make it quite complex to accurately determine the lengths, thus the computer program is an essential tool for this task).

The one *complication* with designing pull-offs in the OHW, is that the catenary and contact heights need to take into account the *track level* throughout that bay (track vertical alignment) – this is only a problem if the track is not on a *constant grade* within the bay.

UNUSUAL ARRANGEMENT

An upgrade to the "Mortdale to Sutherland" fixed-anchored OHW (in the late 1980s?) saw an unusual arrangement used at mid-bay pull-offs, to replace the original mast-to-mast cross-spans for *Independent Registration* (without installing a portal structure) – *Figure 248*.

Figure 248 - Unusual Push-Off arrangement on inside of track curve

Because it pushes the wire away from the mast, it's sometimes referred to as a "push-off".

Although this left-side arrangement includes a short catenary suspension clamp to hold the catenary wire, it can tend to act to *support* the fixed-anchored catenary wire, and in doing so, play havoc with the *virtual span* of the entire wire run. This means any resulting lower virtual span number could lead to the catenary experiencing a wider range of tensions from cold to hot temperatures – more than what was originally designed. This in turn can cause problems with the contact height – not necessarily here, but elsewhere in very long bays without these pull-off arrangements installed. But I would expect this was checked out before changes were made.

In addition, the vertical that holds the heel of the pull-off arms can extend down well below the contact level. So care was needed to ensure this doesn't foul the *Pantograph Gauge*, per the problem shown back in *Figure 202*.

Having said all this, I am not aware of any significant problems occurring with these arrangements over the 10 or so years they were in service. And they did achieve the important outcome of *Independent Registration*.

Fortunately, I understand this area was subsequently renewed and regulated, and these arrangements have been replaced by more accepted cantilevers.

INSULATOR ALIGNMENT

Both the catenary and contact insulators in a pull-off arrangement *should be in vertical alignment with each other*. If the insulators are somewhat displaced and not aligned, it has in the past caused safety problems if traction workers climb near the live equipment and misunderstand what's actually safe.

Figure 249 shows a drawing produced to highlight a potentially *dangerous situation* or "trap" to be avoided. The picture tells it all. Insulator alignment is important.

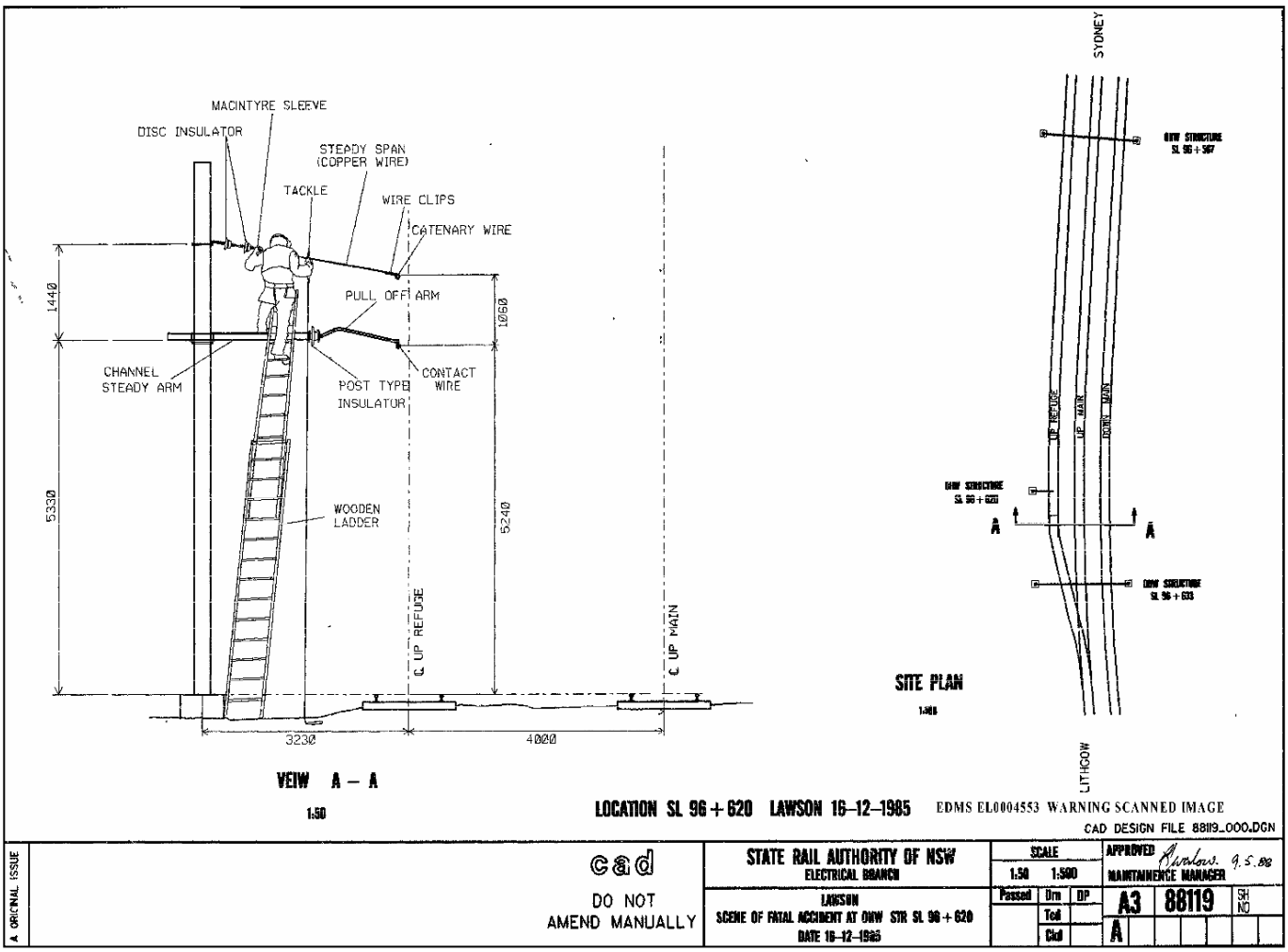


Figure 249 - Pull-Off Insulator alignment danger

HORIZONTAL CATENARY SPAN

Contrary to what's shown on *Figure 249*, the catenary span is ideally meant to be *horizontal*. This way, the span does not affect the catenary profile whatsoever, which is a good outcome.

A catenary span that is at an angle other than horizontal will tend to pull the catenary up (as per above diagram) or drag it down at that span attachment point to the catenary. And the amount of influence on the catenary shape (height) depends on the catenary radial load in the span, with the greater the load the greater the effect on the catenary wire at that point. Any change in catenary height will affect the contact height, unless dropper lengths are somehow altered to correct it locally to its proper level.

PULL-OFF CODING

A coding system exists for newer Mark-2 pull-off arrangements (post 1990s), based on the CCalc coding system (see *Figure 225*), but prefixed with a "P" (included in an oval).

There are several pull-off standard arrangement drawings linked to the code, that show how things are put together (in the same way as CCalc works with the Mark-2 cantilevers).

Example: P+1LMV

3.2.4.6 Status (c. 2014)

The policy for regulated OHW is to generally not use pull-offs. Instead, support the OHW (install cantilevers) wherever possible, as this leads to improved high speed pantograph performance, i.e. less OHW dynamic oscillation, essentially due to the shorter bays.

So, pull-off arrangements are seldom used in new regulated OHW construction (the Mark-2 cantilever arrangement drawings originally did not include any pull-off arrangements, but these were added a few years back in case they could be justified in some rare situations).

Pull-offs may be used in yards, etc. with slow speed traffic, or in situations where their use does not impact on any high speed running.

3.2.4.7 Reference

Refer to *Table 20* and *Table 21* in *Section 3.2* for relevant drawings.

3.2.5 Bridge Arrangements

3.2.5.1 Description

An overline bridge is one that passes over the rail tracks (rail line), and the bridge is predominantly used for road traffic and/or for pedestrians.

Most overline bridges are low, with enough clearance to allow trains to pass underneath. Some additional clearance height is required to squeeze the OHW conductors under while maintaining the necessary electrical clearances (typically 150mm):
from the contact wire down to the passing train, and also
from catenary wire up to the bridge above.

So, OHW bridge arrangements are normally shallow configurations to support and/or register the catenary and/or contact wires with very little system depth (distance between catenary and contact), so these conductors can pass under the bridge. The catenary *T/w* (sag) and bridge height dictate how long the bay lengths can be, and therefore how many support locations are needed through the width of the bridge.

Note: The *ideal* outcome is to have the OHW pass under the bridge *unattached*, but this can only be achieved with narrow or very tall bridges (both seem to be fairly rare).

3.2.5.2 Function

Overline bridge arrangements provide the same functions as other support & registration arrangements, but they do so in the confined spaces normally associated with the catenary and contact wires passing under bridges.

There is normally some provision in the OHW bridge arrangement for some lateral adjustment of catenary and contact wire stagger, but no provision for changing attached catenary heights.

3.2.5.3 Typical Components

The classic bridge arrangement includes the following components:

- "L-iron" fitting (or the older "T-iron" fitting) and catenary attachment clamp, which provides sliding lateral adjustment for catenary horizontal positioning. Fitting Numbers include the 332/- and 932/- series. See *Figure 250*.
- Post type insulators – 2 insulators are needed to support the L-iron or T-iron fitting and associated catenary wire (i.e. 1 insulator located at each end of the iron), and usually 1 insulator for the pull-off arrangement.
- Side strain insulator pair – to register high radial loads on catenary and/or contact wires (instead of the post type insulator mentioned above).

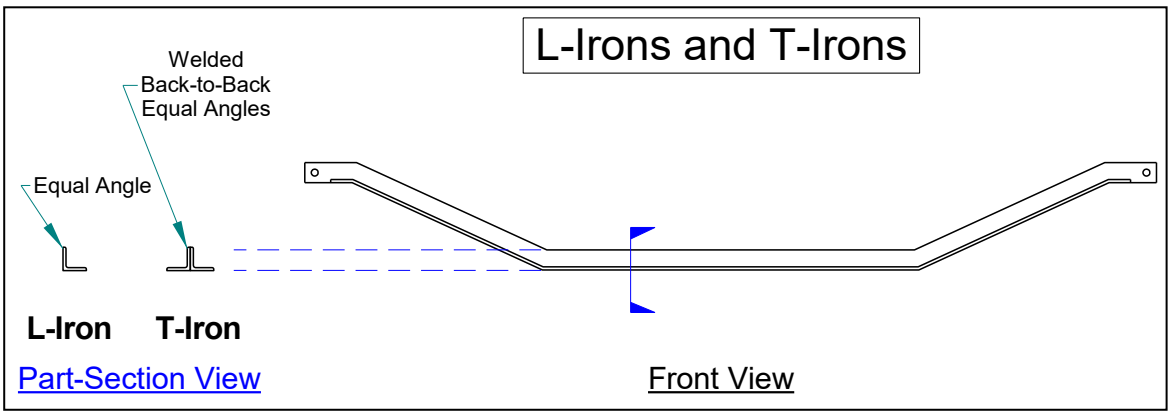


Figure 250 - L-Irons & T-Irons for Overline Bridges

- Catenary fixed clamp – this attaches the catenary to the L-iron, for lateral adjustment.
- Catenary roller arrangement – attached to the L-Iron to support & guide the catenary wire.
- Pull-off arm/s.
- Drop vertical – for mounting the pull-off equipment.
- Insulator channel and attachment fittings to drop vertical.

The bridge arrangements may require special screens at one or both ends of the bridge above the OHW conductors. These are not part of the bridge arrangement as such, but may be required for safety reasons to prevent people coming too close to live OHW conductors – see *Section 3.11* for more information.

3.2.5.4 Configuration

Overline bridges can range from pedestrian foot bridges to road or rail traffic overline bridges, or a combination thereof.

Bridge arrangements typically have to cope with a shallow system depth (vertical distance from catenary to contact), as heights from the track to the underside of the bridge are often very low.

If needed, the attachment of catenary wire to the bridge can be done in a number of different ways. Refer to *Figure 726* in *Appendix 10.1* for one such Overline Bridge Arrangement drawing (at Chatswood).

Suspension Angle

The catenary is usually supported by attachment to the middle of a long "Suspension Angle".

This is usually either an "L-iron" or "T-iron" fitting (up to 3 metres long), which itself is supported at each end by a post type insulator.

The L-iron and T-iron fittings are named by virtue of their cross-sectional shape (*Figure 250*). An L-iron refers to the "L" shaped cross-section of *equal angle* steel (of suitable length), whereas a "T-iron" typically refers to the inverted "T" shape formed by welding 2 such equal angles back-to-back, thus providing a stronger section of steel. L-irons seem to be far more prevalent throughout the electrified network, likely due to their simplicity.

The vertical depth of the cranked L-iron is for achieving a particular catenary wire attachment height. This depth is often a variable and is dependent on the specific bridge situation.

These suspension angles place both of the attached post type insulators into compression, with the cap on the OHW side. In this configuration, the cap corrodes in preference to the base, which is desirable because of the much greater surface area on the steel cap compared with the thinner steel "tongue" section on the base. This approach yields a longer service life. You can see some corrosion (brown stains) taking place on the upper porcelain surface in *Figure 256* (further on).

It is also thought that, if lightning damages the ceramic post type insulator (fitting 452) and causes it to "pop" (break), the insulators, being in compression, would more likely allow the supported L-iron or T-iron to remain intact and not drop into the path of a train. No guarantees though. See *Section 3.2.5.5, Lightning* further down for more information, and especially *Figure 262*.

For simplicity, I will refer to either unit as just an L-iron (rather than repeat the T-iron equivalent).

One of the big advantages of the L-iron fitting is the usually large amount of catenary horizontal stagger adjustability, which is important when it cannot be placed under the bridge

in the correct position (due to interference with other bridge beams). Sadly, there is no convenient vertical adjustment for changing catenary height.

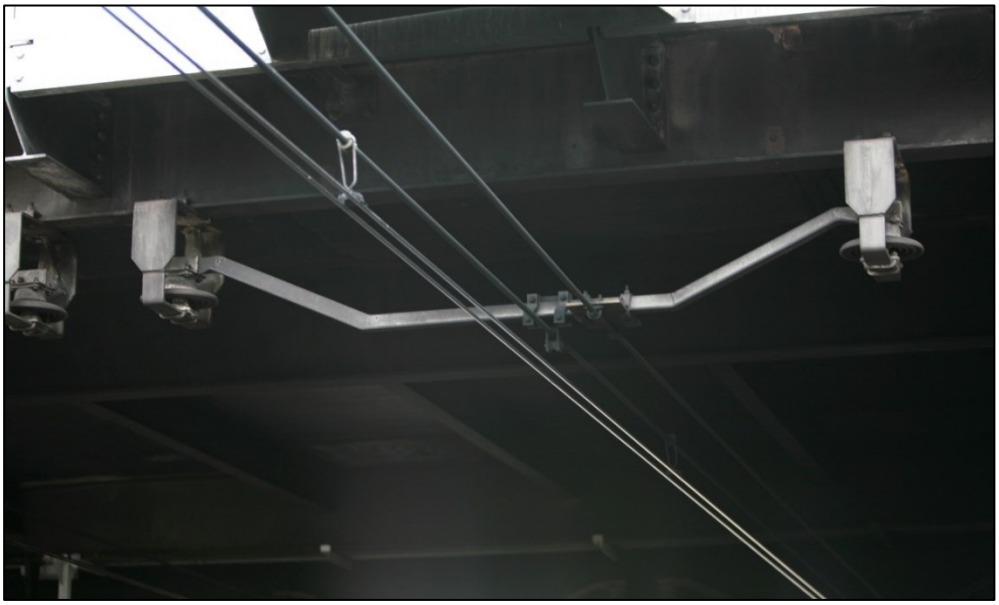


Figure 251 - L-iron with Catenary Rollers and Auxiliary Feeder

The L-Iron can also allow for more than 1 catenary wire to be installed, and also an auxiliary feeder can be added with little complication, provided the additional mechanical loads have been checked out during the design phase, and any current feeding through the L-iron is not deemed an issue.

Figure 251 is a case in point, with an auxiliary feeder installed next to the main catenary wire (supporting twin contacts). Feeder jumpers from catenary to auxiliary feeder would be needed nearby to lessen the amount of current transfer through the L-Iron.

BRIDGE CLAMP

For fixed-anchored OHW, a cast gunmetal "bridge clamp" (Fitting 187/- series) is used to clamp around the catenary wire with single bolt to fasten the catenary, and with 2 holes that enable the clamp to be connected to the bridge L-Iron and lock it in place. The clamp is designed to hold the catenary without damaging any of the copper strands.

The bridge clamp assembly can be positioned anywhere along the straight horizontal part of the L-Iron.

CATENARY ROLLERS

In cases of *regulated* OHW, where the catenary wire needs to move longitudinally, under certain circumstances a *catenary roller* arrangement can be used instead of the "fixed" bridge fitting (which locks the catenary wire).

The catenary roller arrangement has 2 plastic "delrin" rollers or more recently brass rollers – one located above and one below the catenary. These rollers help to trap the catenary wire and prevent the catenary from sagging (providing weight on the L-Iron) or rising (providing uplift) at that point. In doing so, the catenary height remains constant, which is desirable.

See *Figure 252* for an example using white delrin rollers, and *Figure 253* with brass rollers.

The rollers are designed to support a small amount of wire weight (or uplift), and importantly can be used to guide the catenary's lateral (stagger) position. Care should be exercised to ensure that any lateral change in direction of the catenary wire at the roller is not too great, as this may cause side wear against the steel side plates, leading to fatigue of the catenary strands over time.

Figure 252 - Catenary Rollers (Delrin)

The amount of wire weight, or lift, at the rollers is normally limited to that resulting from about 10m to 15m of wire length (i.e. the distance between adjacent catenary low points, which is depicted further on in *Figure 263*). It is considered that any more than this total length makes the progressive and cyclic change of catenary angle at the rollers too great as it passes through the rollers several times a day every day of the year. Fatigue is the main concern here.

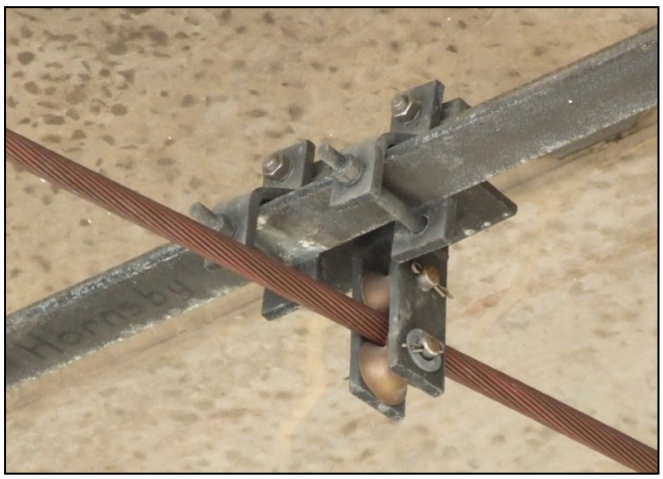


Figure 253 - Catenary Rollers (Brass)

Often associated with the catenary rollers is a catenary pull-off arrangement which handles any catenary radial load, and allows the controlled alignment of catenary wire through the rollers during wire movement due to temperature changes. The rollers are not designed to take any significant sideways force (due to radial load). Refer to the span arrangement to catenary in *Figure 254*.

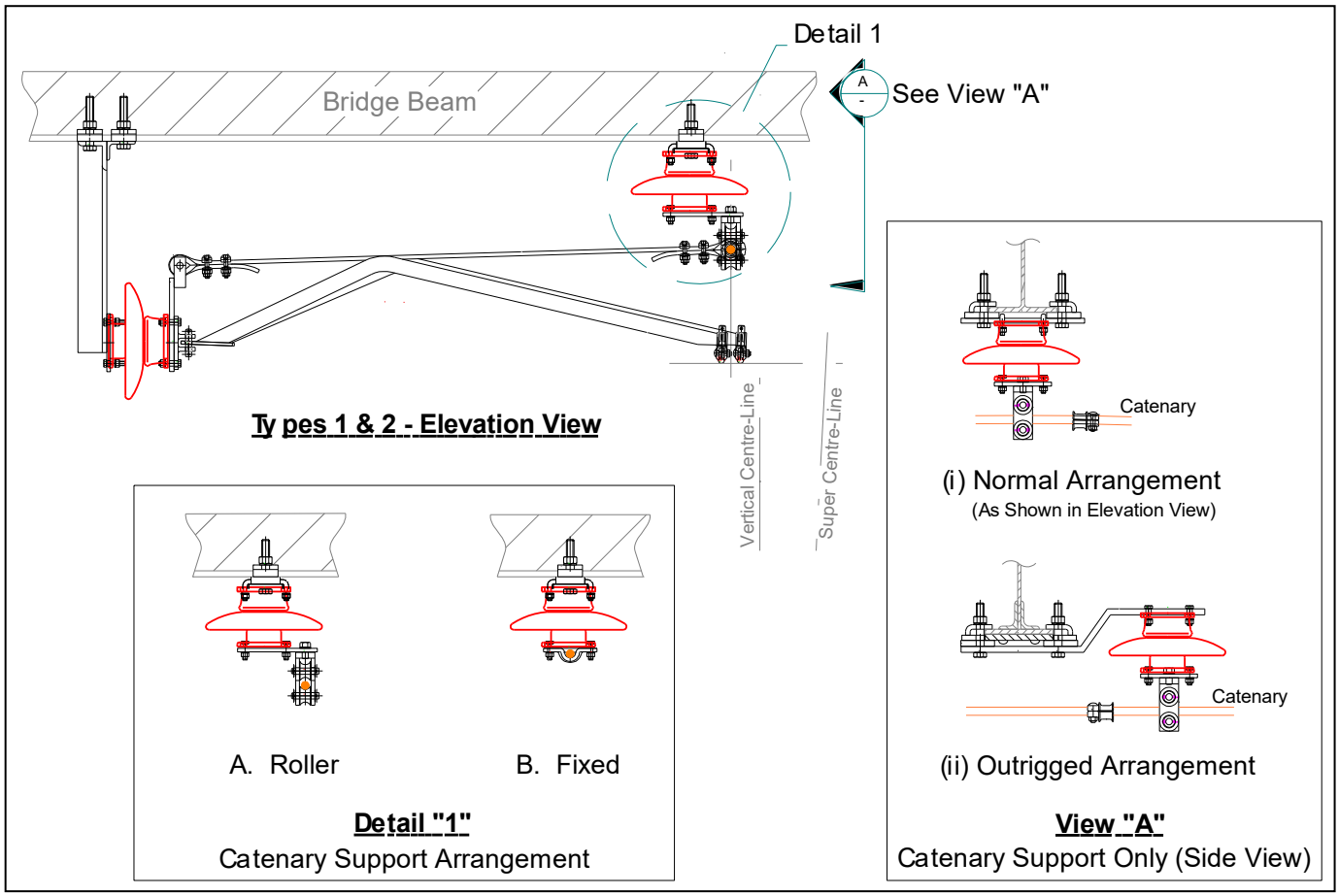


Figure 254 - Bridge Arrangement for Regulated OHW

A 16mm set screw located in the centre top of the roller arrangement connects the rollers to a steel plate, which then clamps around the L-iron (providing lateral position adjustment). Importantly, this configuration enables the fitting to be rotated about its vertical axis so that the roller side plates can be positioned clear of the catenary wire, before being locked into place by tightening the set screw.

Figure 254 is an arrangement that does not include any L-iron, but instead simply clamps the post type insulator onto the bridge beams. It was developed for the limited space at Central Flyunders for the (then new) regulated OHW system in the early 2000s.

This arrangement was designed for relatively low radial load situations, and incorporates both a "Roller" (for moving wire) and a "Fixed" catenary connection (as shown in Detail 1) at any fixed mid-point locations.

Figure 255 shows a similar arrangement for the same project but was designed for higher radial load situations.

Note:

Catenary rollers made from *brass* may tend to flatten the outer strands of the catenary wire as this wire bears weight (or uplift) whilst moving a limited distance longitudinally through the rollers several times a day. (This was less likely an issue with the earlier plastic *delrin* rollers.)

So, in cases of significant weight loading, the Mk-2 or Mk-3 Tunnel Cantilevers may now offer a better long-term solution, if the specific situation allows sufficient space for their incorporation.

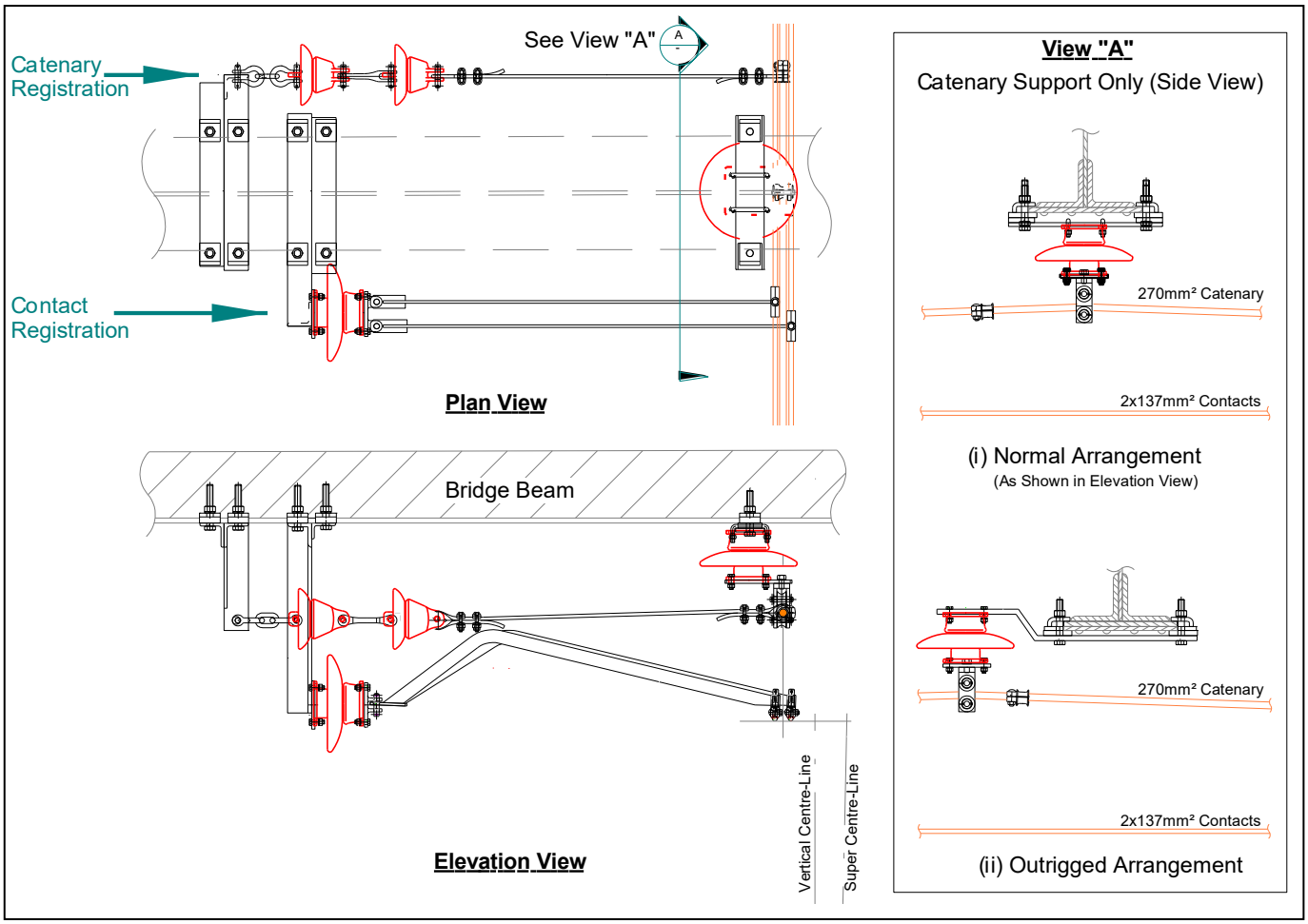


Figure 255 - Bridge Arrangement for Regulated OHW

Figure 256 - "L-iron" and Pull-Off Arrangements on Bridge

SECONDARY INSULATION

In the "old days" they used to sometimes add another layer of insulation sandwiched between the catenary and the L-iron or T-iron, seen as a flat rectangular plate in *Figure 257*. I am not absolutely sure why this was used (and am not aware if it being installed nowadays).

However, I was once told that this plate had probably saved the life of one painter who wrongly thought it was OK to stand on the conveniently placed L-iron when painting the outside of a particular bridge! A lucky man, and fortunate that someone saw him in time. In this extremely dangerous situation, the L-iron would have been at some "floating" potential, and his boots may have also helped a little to isolate him from harm.

It may have been that this was a problem at some particular time for certain bridges where trying to restrict access was a proven issue (as described above), and a quick and cheap improvement might have been to install an insulation plate (which unfortunately would have also reduced the catenary and contact height by about 12mm in these height-restricted areas). *However, this reasoning is only a guess.*

It may also have been used to help improve the lightning flashover in these situations. (Lightning often flashed over at bridges with reduced catenary clearances.) Or maybe to further minimise any electrolysis leakage currents to the bridge?

It's interesting to note that the isolated catenary wire in *Figure 257* has an auxiliary catenary clamped next to it with no apparent insulation plate, so the L-iron would then be alive and the catenary insulation plate is thus most likely rendered useless here. But maybe it's to prevent feeding current passing between catenary and auxiliary feeder across the L-Iron and possibly damaging something over time? I don't know for sure, but can only guess.

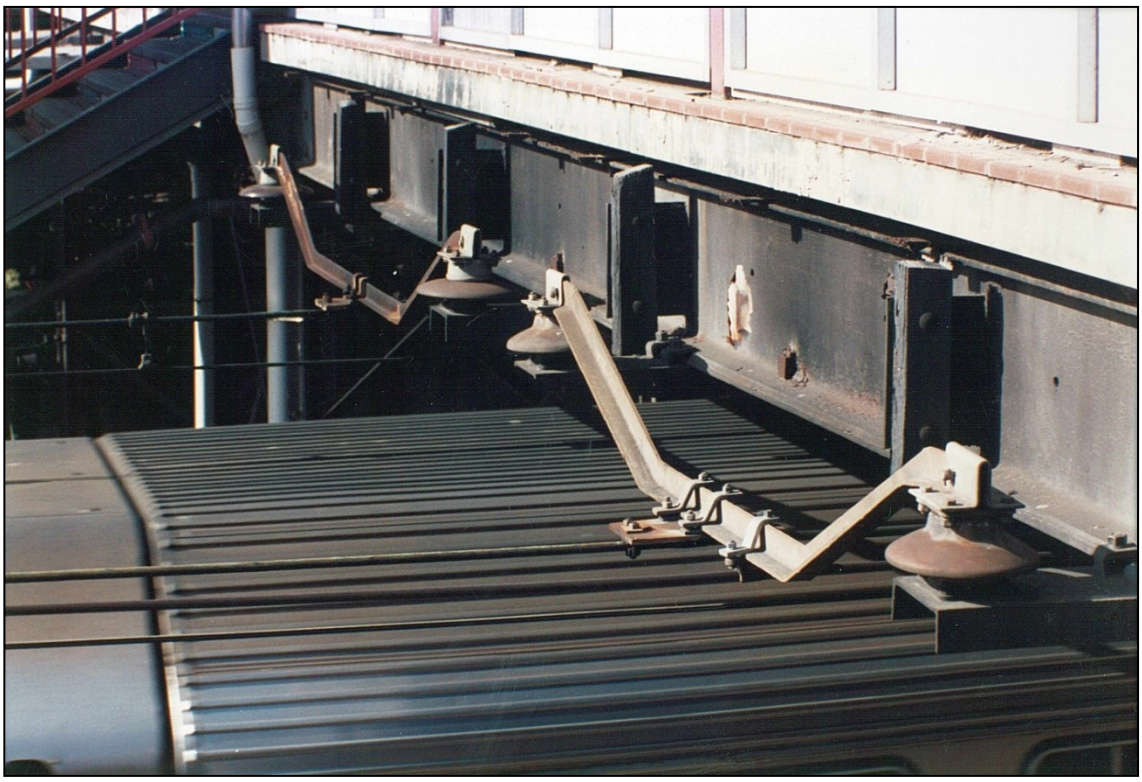


Figure 257 - Typical Bridge Support & Registration arrangement

Figure 258 shows a clever arrangement that attaches the contact registration onto the L-iron fitting. This provides a degree of contact stagger adjustment which can be quite convenient (as with the catenary). However, this arrangement is probably only suited to small radial loads, and should be checked out during its design to ensure that it won't overload the whole configuration, and won't cause excessive deflection in the L-iron fitting itself.

In a fixed-anchored system the contact wire tension changes dramatically with temperature, and the contact radial load is proportional to its tension, so the likely change of deflection on the L-iron may also need to be looked at for suitability under the temperature extremes.

Aside: Again, referring to *Figure 258* – when does a "bridge" become a "tunnel"?

Figure 258 - Contact Pull-Off attached to L-iron

3.2.5.5 Design Notes

It is fortunate that Sydney's electrified network only has a handful of *public level crossings* remaining. However, there are quite a few *private level crossings* scattered through the network, but the volume of traffic crossing these would be way less than for public crossings.

With few public level crossings, it means that there are many more overline bridges that have taken their place. So, the OHW network includes a huge population of overline bridge arrangements that support and register the OHW under the bridge. This is a small price to pay for the superior outcome of removing level crossings.

See *Section 6.4.5* for more information on *Level Crossings*.

Note:

Many of the design requirements when dealing with overline bridges (and tunnels) are stipulated in EP-08000001-SP, "OHW Standards for the Electrification of New Routes".

LOADING ON L-IRONS

The L-irons (and T-irons) must be capable of supporting the weight of some of the bay of OHW, and of holding the catenary wire longitudinally in place if fixed. Often, there is also some radial load on the catenary, so any fixed catenary clamp onto the L-iron needs to be firmly locked in place to prevent it sliding laterally along the L-iron.

The OHW loading onto the L-iron has to be limited, partly because the L-iron can flex over

its significant length. The weight of OHW supported on the L-iron is determined by the distance between the 2 adjacent catenary low points – one on the Sydney side and the other on the country side of the L-iron, per *Figure 263*. So, if the OHW lowers when approaching the bridge, the catenary low point is normally designed to be close to the first L-iron, to help limit this weight load. (Note that the location of the low points can move at different catenary tensions in a fixed-anchored OHW system, thus affecting the weight load.)

Loading on the L-irons is an important aspect in the OHW design phase.

L-IRON BENEFITS

Sometimes the design for the installation of an L-iron is difficult to achieve (especially regarding how to go about supporting the 2 post type insulators from the bridge beams).

But the big benefit of this arrangement is the ability, if designed properly, to place the supported catenary wire at the correct restricted height and allow for quite *a large amount of lateral catenary stagger adjustability*, to achieve the correct catenary stagger.

OHW ATTACHMENT TO BRIDGE (OR NOT)

When designing OHW that passes under a bridge, the aim should be to avoid attaching any support & registration arrangements to the bridge itself, i.e. to pass under *unattached*. Refer to *Figure 259* for example. This then reduces the likelihood of the need for any bonding circuit (except if horizontal safety screens are installed and need to be bonded).

Bonding the S&R equipment is expensive, it has to be maintained into the future, and it increases the chance of electrolysis complications (if some of the equipment gets damaged or is improperly installed or maintained, or if the spark gap shorts out for extended periods).

Figure 259 - New OHW passing under a bridge "Unattached"

Figure 259 shows tall steel barriers installed on the bridge (both sides) to prevent people on the bridge from causing problems to the tracks & infrastructure below. (I think these barriers

are called "bat wings" because of their shape when viewed on the road).

But passing through unattached requires something like 450mm minimum clearance from catenary to the underside of the bridge. (This clearance depends on the distance from bridge to the next catenary support location – see the Electrification Standard EP-08000001-SP.)

In most cases, this large clearance cannot be achieved, so the OHW would then need to be attached at one or more locations (depending on the width of the bridge).

Of course, for this to work, there has to still be adequate electrical clearances from the catenary to the underside of the bridge, as per the Electrification Standard. The clearances take into account some level of dynamic wire movement due to the passing trains, etc., and wire height changes due to temperature changes if it's fixed-anchored OHW.

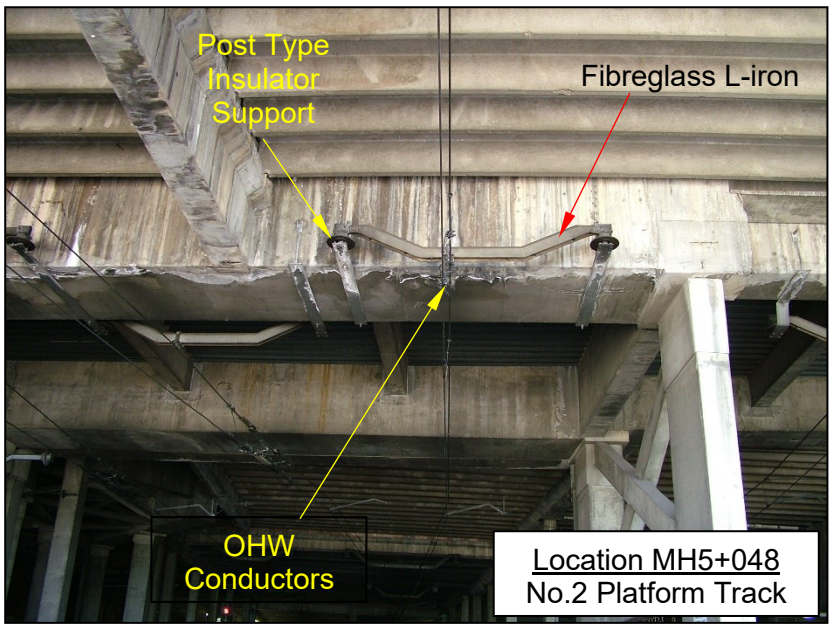


Figure 260 - North Sydney Air Space - Fibreglass L-irons

Figure 260 shows an older instance where the T-irons were made from fibreglass, which provided a huge amount of insulation in addition to the post type insulators installed each side to support it. (Note that this situation has since been changed to a Tunnel Cantilever, per *Figure 478*.)

BRIDGE ARRANGEMENT CODING

Recently, where practical, it was decided to try to include a generic "Bridge Arrangement Coding" for the support & registration arrangements installed on an overline bridge (similar to the CCalc coding and Pull-Off coding systems), and reference this coding on layouts.

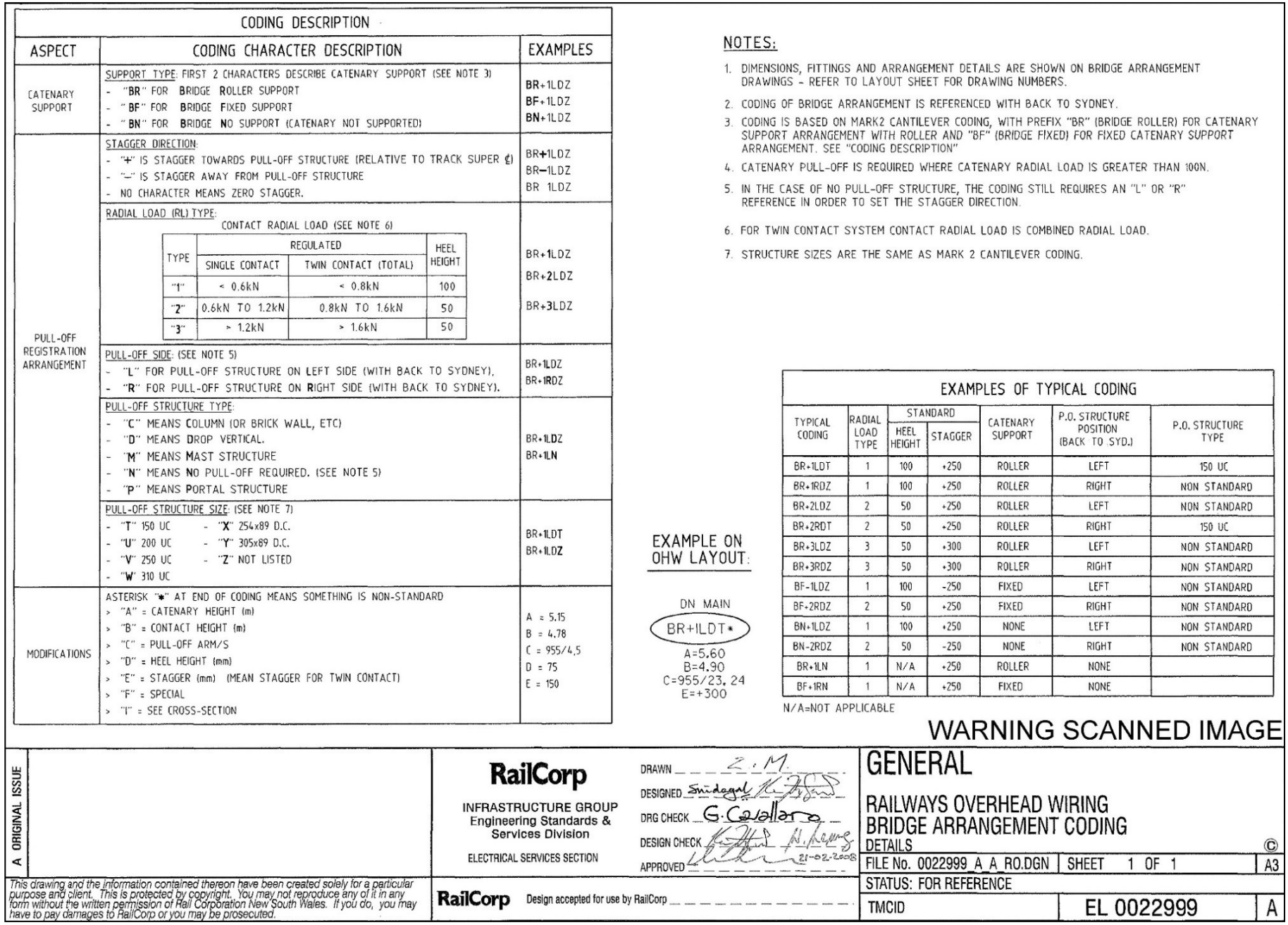
Although it seems that no two bridge S&R arrangements are the same, and that without standard arrangements, the coding cannot describe the physical nuts & bolts make-up of the arrangement, at least the coding can convey some vital information on OHW layouts to those people who wish to know a bit more about what's going on at that important S&R location.

Included are vital things such as the catenary height, the contact height and stagger, heel height, etc. Also indicated is whether the catenary support is fixed in position or has rollers that allow a regulated catenary to move with temperature changes. The other aspect is a reference to the drawing that shows the "nuts & bolts" physical arrangement of what is to be (or was) built.

Refer to drawing EL0022999, shown in *Figure 261*, which describes the generic bridge S&R coding system.

Example: BR+1LDT

A=5.60
B=4.90
C=955/23,24
E=+300



CODING DESCRIPTION

ASPECT	CODING CHARACTER DESCRIPTION	EXAMPLES
CATENARY SUPPORT	SUPPORT TYPE: FIRST 2 CHARACTERS DESCRIBE CATENARY SUPPORT (SEE NOTE 3) - "BR" FOR BRIDGE ROLLER SUPPORT - "BF" FOR BRIDGE FIXED SUPPORT - "BN" FOR BRIDGE NO SUPPORT (CATENARY NOT SUPPORTED)	BR+1LDZ BF+1LDZ BN+1LDZ
PULL-OFF REGISTRATION ARRANGEMENT	STAGGER DIRECTION: - "+" IS STAGGER TOWARDS PULL-OFF STRUCTURE (RELATIVE TO TRACK SUPER ℄) - "–" IS STAGGER AWAY FROM PULL-OFF STRUCTURE - NO CHARACTER MEANS ZERO STAGGER.	BR+1LDZ BR–1LDZ BR 1LDZ
	RADIAL LOAD (RL) TYPE: CONTACT RADIAL LOAD (SEE NOTE 6)	BR+1LDZ BR+2LDZ BR+3LDZ
	PULL-OFF SIDE: (SEE NOTE 5) - "L" FOR PULL-OFF STRUCTURE ON LEFT SIDE (WITH BACK TO SYDNEY), - "R" FOR PULL-OFF STRUCTURE ON RIGHT SIDE (WITH BACK TO SYDNEY).	BR+1LDZ BR+1RDZ
	PULL-OFF STRUCTURE TYPE: - "C" MEANS COLUMN (OR BRICK WALL, ETC) - "D" MEANS DROP VERTICAL. - "M" MEANS MAST STRUCTURE - "N" MEANS NO PULL-OFF REQUIRED. (SEE NOTE 5) - "P" MEANS PORTAL STRUCTURE	BR+1LDZ BR+1LN
	PULL-OFF STRUCTURE SIZE: (SEE NOTE 7) - "T" 150 UC - "X" 254x89 D.C. - "U" 200 UC - "Y" 305x89 D.C. - "V" 250 UC - "Z" NOT LISTED - "W" 310 UC	BR+1LDT BR+1LDZ
MODIFICATIONS	ASTERISK "*" AT END OF CODING MEANS SOMETHING IS NON-STANDARD > "A" = CATENARY HEIGHT (m) > "B" = CONTACT HEIGHT (m) > "C" = PULL-OFF ARM/S > "D" = HEEL HEIGHT (mm) > "E" = STAGGER (mm) (MEAN STAGGER FOR TWIN CONTACT) > "F" = SPECIAL > "I" = SEE CROSS-SECTION	A = 5.15 B = 4.78 C = 955/4.5 D = 75 E = 150

TYPE	REGULATED		HEEL HEIGHT
	SINGLE CONTACT	TWIN CONTACT (TOTAL)	
"1"	< 0.6kN	< 0.8kN	100
"2"	0.6kN TO 1.2kN	0.8kN TO 1.6kN	50
"3"	> 1.2kN	> 1.6kN	50

NOTES:

1. DIMENSIONS, FITTINGS AND ARRANGEMENT DETAILS ARE SHOWN ON BRIDGE ARRANGEMENT DRAWINGS - REFER TO LAYOUT SHEET FOR DRAWING NUMBERS.
2. CODING OF BRIDGE ARRANGEMENT IS REFERENCED WITH BACK TO SYDNEY.
3. CODING IS BASED ON MARK2 CANTILEVER CODING, WITH PREFIX "BR" (BRIDGE ROLLER) FOR CATENARY SUPPORT ARRANGEMENT WITH ROLLER AND "BF" (BRIDGE FIXED) FOR FIXED CATENARY SUPPORT ARRANGEMENT. SEE "CODING DESCRIPTION"
4. CATENARY PULL-OFF IS REQUIRED WHERE CATENARY RADIAL LOAD IS GREATER THAN 100N.
5. IN THE CASE OF NO PULL-OFF STRUCTURE, THE CODING STILL REQUIRES AN "L" OR "R" REFERENCE IN ORDER TO SET THE STAGGER DIRECTION.
6. FOR TWIN CONTACT SYSTEM CONTACT RADIAL LOAD IS COMBINED RADIAL LOAD.
7. STRUCTURE SIZES ARE THE SAME AS MARK 2 CANTILEVER CODING.

EXAMPLE ON OHW LAYOUT:

DN MAIN

BR+1LDT*

A=5.60
B=4.90
C=955/23.24
E=+300

EXAMPLES OF TYPICAL CODING

TYPICAL CODING	RADIAL LOAD TYPE	STANDARD		CATENARY SUPPORT	P.O. STRUCTURE POSITION (BACK TO SYD.)	P.O. STRUCTURE TYPE
		HEEL HEIGHT	STAGGER			
BR+1LDT	1	100	+250	ROLLER	LEFT	150 UC
BR+1RDZ	1	100	+250	ROLLER	RIGHT	NON STANDARD
BR+2LDZ	2	50	+250	ROLLER	LEFT	NON STANDARD
BR+2RDT	2	50	+250	ROLLER	RIGHT	150 UC
BR+3LDZ	3	50	+300	ROLLER	LEFT	NON STANDARD
BR+3RDZ	3	50	+300	ROLLER	RIGHT	NON STANDARD
BF-1LDZ	1	100	-250	FIXED	LEFT	NON STANDARD
BF+2RDZ	2	50	+250	FIXED	RIGHT	NON STANDARD
BN+1LDZ	1	100	+250	NONE	LEFT	NON STANDARD
BN-2RDZ	2	50	-250	NONE	RIGHT	NON STANDARD
BR+1LN	1	N/A	+250	ROLLER	NONE	
BF+1RN	1	N/A	+250	FIXED	NONE	

N/A=NOT APPLICABLE

WARNING SCANNED IMAGE

A ORIGINAL ISSUE

RailCorp
INFRASTRUCTURE GROUP
Engineering Standards & Services Division
ELECTRICAL SERVICES SECTION

DRAWN Z.M.
DESIGNED Swidegard
DRG CHECK G.Cavallaro
DESIGN CHECK N.Lewis
APPROVED 21-02-2008

GENERAL

RAILWAYS OVERHEAD WIRING
BRIDGE ARRANGEMENT CODING
DETAILS ©

FILE No. 0022999_A_A_RO.DGN | SHEET 1 OF 1 | A3

STATUS: FOR REFERENCE

TMCID | EL 0022999 | A

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Figure 261 - Bridge Support & Registration Coding details

LIGHTNING

Because of the necessarily reduced electrical clearances under most overline bridges where the OHW is attached to the bridge, the OHW support equipment can be more susceptible to lightning flashover and subsequent damage. This is even if the length of the post type insulators (155mm) forces a clearance slightly greater than the minimum 150mm required – lightning can readily cause flashover to occur.

I was told that there were problems at bridges early on, where lightning would sometimes flashover at the porcelain post type insulators (fitting 452) and cause them to "pop" (break apart). Refer to *Figure 262*, showing one such popped insulator at Doonside in 2000 (probably from lightning damage).

Figure 262 - A "popped" ceramic Post Type Insulator

Apparently in the very early days, in at least some cases, the L-iron was *suspended* under the insulator (with one insulator at each end of the L-iron, as usual). This typically caused both insulators to be in tension, when holding up the weight of the L-iron and associated attachments, as well as a small amount of OHW conductor weight load.

Unfortunately, in that configuration, when an insulator popped (and with the insulator at the other end of the L-iron still intact), the L-iron and associated hardware could then swing down and into an elevated position in the path of an oncoming train.

In this scenario, the OHW could possibly still remain alive at 1500V (if nothing touched any bridge steelwork), meaning that the driver of an oncoming train may be oblivious to any problem further ahead. The damaged L-iron hardware could even be lowered and then supported by the OHW itself, because the bridge attachment is often located close to the low point of the catenary.

Apparently, this problem happened a few times, which was obviously quite concerning and needed a solution.

So, at some stage the design was changed to put the insulator into *compression*, by pinning the L-iron to the top of the insulators (instead of the bottom), and this probably necessitated the characteristic deep-set shape of the L-iron we see today. See *Figure 257* for instance of this typical configuration.

Apparently this change was made so that, if the insulator popped, the L-iron would be more likely to remain roughly in place, although probably shorting out to the steel stirrups supporting the insulator from the bridge. This steelwork used to be spark-gapped to rail, causing the dc circuit breaker protection to trip and remain tripped, ultimately stopping trains. This meant that OHW staff were immediately called out to identify and fix the problem. This appears to be a much better outcome than the previous one, especially in terms of damage mitigation (to train and OHW) and safety.

This approach must have also helped with the insulator dc leakage corrosion aspect as well (which was mentioned previously).

VERTICAL LOADING ON L-IRON

The OHW vertical loading held by an L-Iron from an overline bridge (OLB) is a function of the geometry of the catenary attached to it, notably its *low point* (LP) as demonstrated below.

Figure 263 shows 3 situations:

a) ***No Load***. This case has the catenary attached to the L-Iron, but it passes through without changing its parabolic shape at the L-Iron connection. Therefore, there's ***no vertical loading*** from the catenary to the L-Iron.

b) ***Weight Load***. The catenary shape is altered at the L-Iron attachment, such that the distance *between* catenary low points is +15m. With an OHW system weight of 51N/m (say), this translates to $15 \times 51 = 765$N of ***weight*** on the L-Iron.

c) ***Uplift Load***. Here the catenary shape is altered at the L-Iron attachment, resulting in -8m between catenary low points (one of which is projected). The negative number means an ***uplift force***, in this case $-8 \times 51 = -408$N uplift load on L-Iron (or whatever is attaching the catenary wire, through insulation, to the bridge).

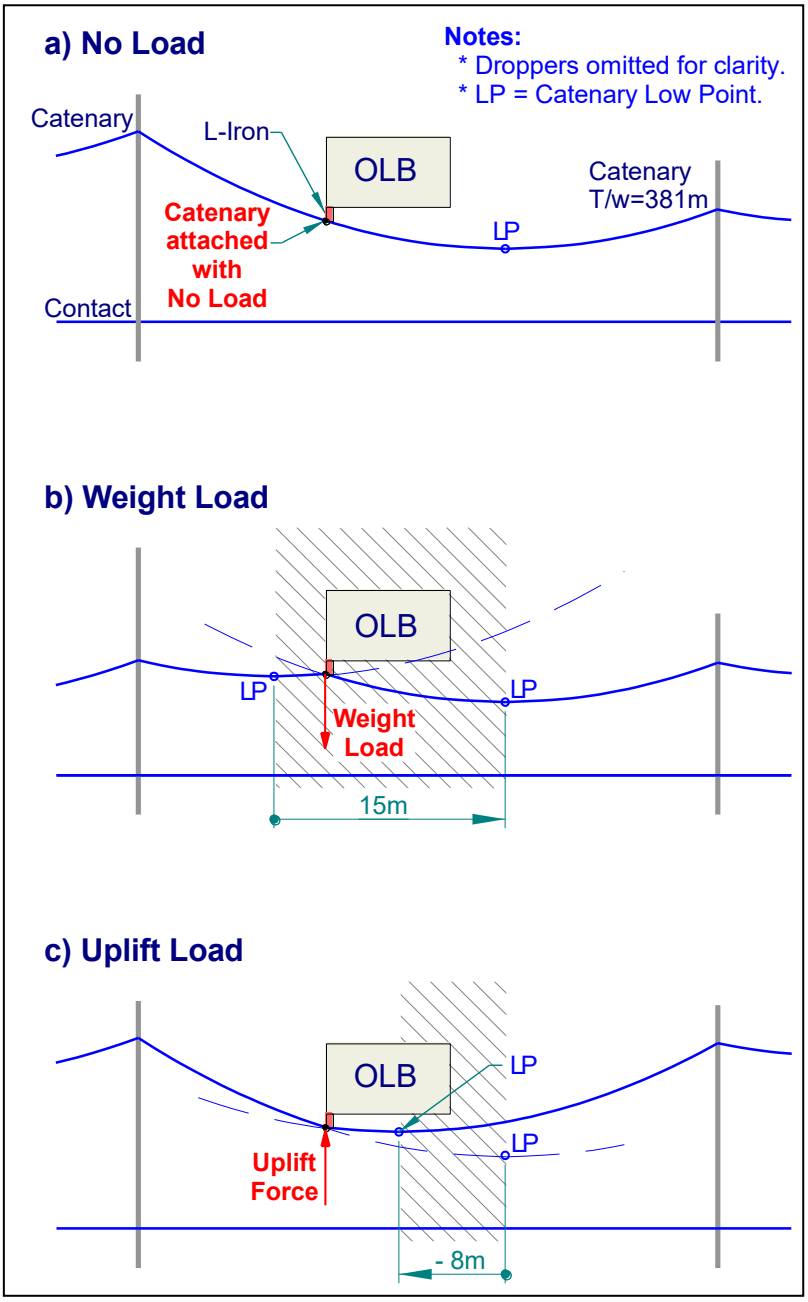


Figure 263 - Three Catenary Loading situations onto bridge L-Iron

Note that the position of the catenary low point depends on the catenary tension. So, if this tension changes, as it will in a fixed-anchored system with temperature changes, then the low points will move about, and thus the amount of uplift or weight on the L-iron will change too.

3.2.5.6 Status (c. 2014)

Current preferred practice is to use the L-iron arrangement, although other options are available (such as a Mk-2 or Mk-3 Tunnel Cantilever – see next Section).

3.2.5.7 Reference

Refer to *Table 20* and *Table 21* in *Section 3.2* for relevant drawings.

3.2.6 Tunnel Arrangements

3.2.6.1 Description

Tunnel support & registration arrangements appear as compact configurations of insulators, arm/s and other hardware that connects to the lining of the tunnel, and holds the OHW in its correct spatial position above the track being serviced.

This equipment is normally spaced with short bay lengths of typically between 15m and 40m, depending on several factors, including the amount of available space above the contact wire for installing the catenary wire.

3.2.6.2 Function

Tunnel arrangements provide the same functions as other support & registration arrangements but, like overline bridge arrangements (described above), they do so in the confined spaces associated with tunnels, and often with an arch-shaped ceiling.

3.2.6.3 Typical Components

The fundamental components to basic fixed-anchored tunnel arrangements include:

- Catenary support steel bracket anchored onto tunnel lining
- Post type insulators for catenary support & contact registration
- Contact registration steel bracket anchored onto tunnel lining
- Pull-off arm/s, which may need to be specially shaped for the confines of the tunnel.

Tunnel cantilevers for regulated OHW (see next section) require a more elaborate arrangement due to the need to allow the catenary and contact wires to move longitudinally with temperature changes.

3.2.6.4 Configuration

Special support and registration arrangements are needed in tunnels to cope with the confined nature and consequent shallow system depths that are necessary in these areas.

However, it seems that no 2 tunnels have the same geometry, and the radius of any tunnel arch (if present) can vary greatly, all of which makes designing a suitable S&R arrangement an interesting exercise. An example of the variety of tunnel shapes is given in the subsection below on the *Airport Line*.

Arched roof tunnels are usually more difficult to support & register the OHW conductors than flat roof tunnels. This is because, although the curve helps to provide additional catenary height, the lower part of the arch curve shape deprives vital space that could otherwise have been used to install "normal" pull-off arrangements. So in these cases, special arrangements have had to be designed to suit that lack of lower space (providing only limited adjustability).

On tightly arched tunnels, quite often the catenary is simply supported using an insulator suspended from the tunnel roof, while the contact has sometimes needed to be registered from a "pocket" cut out of the tunnel profile, in order to mount the pull-off insulator and still gain suitable clearances to passing pantographs. Sometimes these pantographs pass close to the tunnel lining (but they should still be at least 150mm away).

Another common approach is to install specially designed cantilevers, called "tunnel cantilevers", on drop verticals mounted from the tunnel roof or from special brackets installed onto the tunnel lining.

Sometimes there is so little room to install insulators in the pull-off arrangement, that the normal insulator is replaced by a special *insulated pull-off arm* which incorporates an insulated rod (typically fibreglass) as part of the arm. The fibreglass can readily handle the tension caused by contact radial load, but cannot cope with much bending moment.

The spacing between OHW supports (bay lengths) is normally dictated by the available space for the OHW above a train in the tunnel. The resultant shallow system depth (catenary to contact) requires a much smaller structure spacing than would be achieved outside a tunnel, simply to cope with the catenary sag in this limited space. A typical bay length inside a tunnel is between 15m to 30m, whereas they can be as large as 67m or so outside tunnels (in the open track). Of course, track curvature also plays a part in determining the maximum bay lengths inside tunnels.

The configurations of tunnel support & registration arrangements are usually quite different for fixed-anchored OHW (which can be quite simple) compared to regulated OHW (which can be more complex due to the need for the catenary and contact wires to move longitudinally uninhibited with temperature changes).

FIXED-ANCHORED OHW ARRANGEMENTS

Fixed-anchored OHW is often a good choice for tunnels with limited headroom, provided the combined cross-sectional area of copper in the OHW conductors does not cause them to overheat for the loads drawn by the trains in their worst-case operating timetable scenario and ambient conditions.

If more current capacity is required, then additional "auxiliary feeders" installed in parallel can be used to bump up the rating (keep it operating below its maximum allowable operating temperature).

Some examples of fixed-anchored tunnel OHW arrangements are listed below. See *Section 4.1.3* for more details on fixed-anchored OHW systems for tunnels.

City Circle

I may be wrong, but I think that the City Circle comprises just 2 different OHW configurations:

- *Single 270mm² catenary / single 137mm² contact* (OHW System No. 22), and
- *Single 270mm² catenary / single 193mm² contact* (OHW System No. 21).

In the past, the 165mm² catenary may have been used in certain areas, although I can't be sure about this.

Figure 264 is a photo taken inside one of the tunnels (although it's difficult to see the actual OHW, but it gives an idea of the tunnel shape).

The second system above was likely an upgrade to the one above it when the larger 193mm² contact wire size became available (to reduce the OHW resistance and increase current capacity).

There are also some areas were a 270mm² auxiliary feeder is installed, again to help boost the current rating and lower the circuit resistance.

Figure 264 - City Circle single track

The OHW system has the bare minimum equipment needed to support & register the OHW. A simple post type insulator supporting the catenary and another registering the pull-off arm from the side (lateral space permitting).

Figure 265 is a photo taken directly upwards (pardon the lack of contrast) of some of the more usual support & registration equipment installed in breadloaf-shaped tunnels (although the configuration is unusual due to the crossover wiring). The left set of wires is for the Down Shore track near Wynyard, and the right set of wires is for an adjacent crossover.

The catenary is supported from a post type insulator mounted from the ceiling directly above the track (centre of photo). The keen eye will note that this situation appears to be unusual in that the insulator is actually holding the crossover catenary via a diagonal copper span, and it appears the main catenary is clipped to this span.

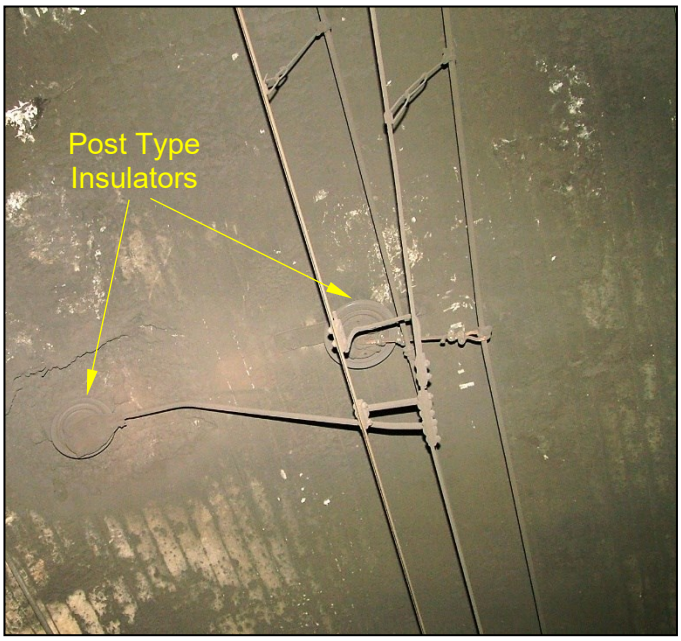


Figure 265 - Typical City Circle S&R equipment (near Wynyard)

The contact wire is registered by a pull-off arm on insulator (on the left side of the track). A shallow pocket was cut into the lining (it's just noticeable on the photo) for mounting the insulator, to increase clearances to the train (it's that tight!). The arm connects to the crossover contact which has a high radial load, and again, the (left) main line contact, with little radial load, is held from this by a steel knuckle.

There are benefits to supporting both the main and crossover catenary at or near one location in this critical situation – this is discussed in *Section 5.1.29*, *OHW Design at Turnouts*.

Each insulator is installed onto a steel strap which is either precast into the tunnel lining or connected to the lining with a bolt at each end of the strap. These bolts were screwed into holes drilled into the concrete lining. In this tunnel, the holes were then packed with "lead wool", which was apparently a common and quite effective method of securing bolts in those days.

The insulators used a pair of standard flat "U-bolts" (fitting 352/- series) to attach to the strap, and this provided a reasonable degree of lateral position adjustment along the strap.

Within the various stations which have more vertical space, twin porcelain suspension insulators would be used for catenary support, and the added length of the insulator string can help the catenary wire gain suitable electrical clearances from the multitude of deep cross beams (which help support whatever's above, typically resulting from the "cut & cover" approach to building underground stations).

For underground island platforms (such as at Wynyard Station) the contact registration can be from solid posts off the walls located adjacent to the tracks.

Alternatively, where the platforms are on the outside of the twin running tracks, span wires can cross from one side of station to the other, over the platforms (e.g. from the arched ceiling of Museum Station – see *Figure 266*). Note that these days, drop verticals suspended from the ceiling, are used to mount the pull-off hardware, which can keep the live infrastructure located close to the trains.

Figure 266 - Simple OHW construction at Museum Station

The big benefit from the simplicity of this OHW system is its reliability. This has been proven over the past almost 100 years since the OHW was originally built in the late 1920s and early 1930s, albeit with some contact wire renewals and minor upgrades over the years. Sadly, overheated wire is the real culprit that affects reliability in fixed-anchored OHW.

Eastern Suburbs Railway

The Eastern Suburbs Railway was completed around 1979, and the OHW for this was a new system:

Single 270mm² catenary / twin 137mm² contacts (OHW System No. 28).

This project has fixed-anchored wiring inside the tunnels, and regulated wiring when outside the tunnels on the various viaducts – using gas tensioners (which have recently been replaced with weight tensioners).

The twin 137mm² contact wires of course deliver a higher current rating than the single 193mm² contact version, but it also provides a superior interface with train pantographs (with the extra contact wire weight helping to control pantograph uplift).

The configurations of support & registration arrangements for these tunnels were similar to that used in the City Underground (with which it interfaces). Use in made of simple single post type insulator or twin suspension insulators supporting the catenary, and likewise for the contact registration (although there were now 2 contact wires to hold).

The twin contact pull-off arms were designed to be lighter than the single contact counterpart, which helped reduce downward pressure and any sparking at the arms when pantographs passed through at speed (especially when the wire tension was low when it was hot).

Note that clever "Delrin Bar" droppers were developed for this line. These had the advantage of pivoting so that it forced both contact wires to be in constant contact with the pantographs, even on highly superelevated tracks (around tight track curves). Refer to *Section 3.1.3* for more details. These droppers were so successful that they remain a standard item.

Further information on this tunnel is given in *Section 4.1.4*.

Airport Line

The Airport Line (or New Southern Railway as it was originally called) was commissioned in 2000 (in time for the Sydney Olympics), and had the same OHW system as the Eastern Suburbs Railway. Refer to *Figure 267*, *Figure 268* and *Figure 269* which show photos of some of the final product.

The tunnel is a single bore, twin track tunnel throughout, and is about 10km long. The first 2.4km was constructed using mechanical road headers in the hard rock section from Central (resulting in various "breadloaf" shaped standard cross-sections). Then a tunnel boring machine (TBM) generated a circular bore (constructed with segmented arc sections) in the subsequent 6km of soft ground (resulting in a circular cross-section bore, as shown in *Figure 267*). Then a crossing under the Cooks River and again under the Main Illawarra tracks near the end, giving a rectangular cross-section, as shown in *Figure 291*. It contained 5 underground railway stations, with the last being below ground but open to the air, resulting in some significant OHW challenges, discussed later.

So, this project had a multitude of tunnel shapes on which to mount suitable S&R arrangements. They included 3 standard "breadloaf" tunnel shapes (types A, B & F), the twin-track Tunnel Boring Machine tunnels which are circular with common diameter (see *Figure 267*), "cut & cover" flat ceilings, various Station flat ceiling profiles (including deep beams spanning above/across the tracks), and another hard rock tunnel shape. There were also some non-standard tunnel shapes, such as encountered at the TBM exit shaft (providing a non-uniform "shotcrete" tunnel lining), and several steel portal bridges spanning side to side through Wolli Creek Station. This all made for an interesting mix of S&R solutions.

Figure 267 - Airport Tunnel S&R arrangements – circular TBM tunnel

The project adopted a design temperature of 25°C (instead of 21°C as used previously). The higher design temperature was closer to a midway temperature between the hot and cold (10°C) temperatures inside the tunnel. This in turn enabled longer bay lengths and a more optimised OHW design, requiring fewer S&R locations and this minimised the amount of equipment (which was one of the contract requirements).

This project saw the extensive use of cycloaliphatic resin insulators for both catenary support (as shown in *Figure 269*) and for contact registration. This insulator technology was new at the time.

The various support & registration standard arrangements developed for this project led to a comparatively simple system in terms of fittings, and most fittings were already standard kit for the rest of the electrified network. Very few special fittings needed developing, which was a good outcome in terms of keeping spares for subsequent maintenance of the line.

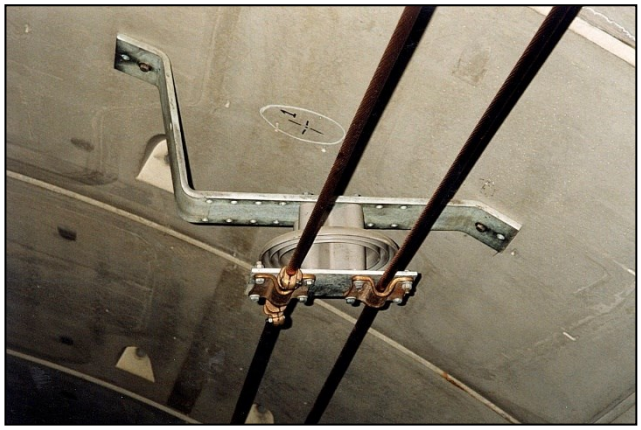


Figure 268 - Catenary & Aux. Feeder supported on Post Type Insulator

A coding system was developed for describing each S&R arrangement, along the lines of that used for Mk2 Cantilevers.

The catenary was mostly supported by post type insulator installed on a solid steel bracket with multiple holes (for discrete catenary stagger adjustment) and the bracket was solidly anchored to the concrete with 2 fasteners. See *Figure 268*. At stations where ceiling heights were greater, a pair of suspension insulators were used, suspended from a steel angle bracket which was anchored to the concrete with 2 fasteners.

The pull-off was either from a wall-mounted steel bracket or from the drop vertical usually located between tracks. A post type insulator attached the twin pull-off arms.

A late change in specification during the project, from running 8 trains per hour to 12 trains per hour, caused a greater proportion of the line to include an auxiliary feeder in parallel with the main wire, as shown in *Figure 268*. This was easily accommodated. The additional 270mm² auxiliary feeder (same size as the catenary) was supported 216mm to one side or other of the catenary at the supports. Indeed, even this wasn't enough copper in the air for the Down track run through Wolli Ck Station, so 2 auxiliary feeders were added to keep the maximum temperatures in check. In terms of copper cross-sectional area, this is $3\times270\text{mm}^2 + 2\times137\text{mm}^2 = 1{,}084\text{mm}^2$ of copper, which is a huge amount. In explanation, Wolli Ck Station is located under ground level but is exposed to the sun – so there's direct solar radiation but with no cooling cross winds, meaning that the various OHW conductors heat up to higher temperatures than if they were located outside, above ground and in the open.

Well before any trackwork was installed, the OHW fittings were progressively being installed with the help of survey marks as shown in *Figure 268* (note the marked black cross hairs and number "1" above the post type insulator).

These survey marks were located from eastings and northings obtained from the CAD-generated OHW layout. When marked, the surveyor fed back the height (relative level), which then gave an accurate 3-D location of the mark. The catenary height could then be either determined or set relative to the design track position at that location, and all other details of the support & registration arrangement could be calculated that would then deliver the correct and all-important design contact height and stagger (within their stipulated tolerances).

A spreadsheet program (written in Visual Basic for Applications language) took the S&R coding to point to various standard arrangements. This helped to automate the process of calculating the huge amount of construction details for all support & registration arrangements in any particular wire run from anchor to anchor. The time taken to develop this program was well worth it as it was used extensively, especially when a subsequent resurvey was carried out of the as-built position of all installed tunnel brackets. All S&R details were then recalculated before all dropper lengths were made and the catenary and contact wires were run. This approach led to minimal adjustments and an accurate end result.

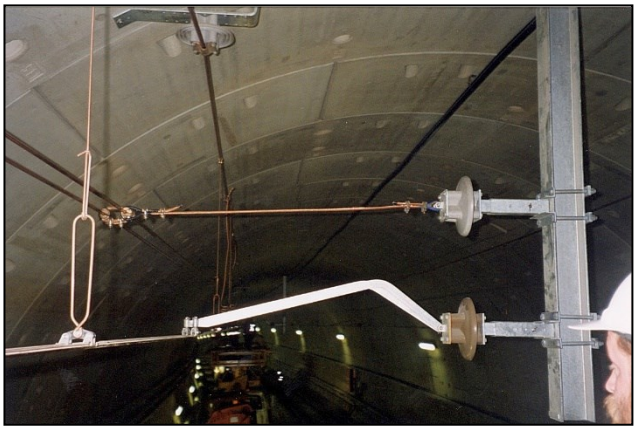


Figure 269 - Out-Of-Running & In-Running Pull-Off Registration

A follow-up audit carried out in 2014 showed the OHW to be performing well, with very few problems.

One problem was accelerated corrosion on some of the galvanised steel support brackets due to water leakage through the hard rock tunnel located between Central and Green Square (mostly at the Central end where the tunnel was shallower below ground).

For more information on the Airport Line refer to *Section 4.1.5* later in this document.

Figure 270 - OHW & Track Construction on the new Airport Line

Epping to Chatswood Line

The Epping to Chatswood Tunnel OHW was built around 2007 and, like the Airport Line before it, was based on the ESR OHW (System No. 28). The design temperature was again set at 25°C for a more optimal solution. This tunnel comprised twin smaller tunnels all the way (which was a policy shift away from single twin-track tunnels, apparently due to safety egress concerns, etc.).

Figure 271 shows a few bays of single catenary / twin contact OHW with an accompanying 270mm² auxiliary feeder located next to the catenary.

This system is currently "converted" for the new automated NorthWest Metro line commencing in 2019 with single deck trains only. It operates at the same 1500V dc supply, so it remains to be seen what changes (if any) were required for the OHW in this particular tunnel from Epping to Chatswood.

Further information on this tunnel is given in *Section 4.1.6*.

Figure 271 - Epping to Chatswood Tunnel OHW system

Compound OHW

The inclusion of a third wire – the auxiliary catenary sandwiched between catenary and contact wires – ideally required more vertical space under bridges and inside tunnels. This had led to some significant clearance challenges, and some novel solutions were developed.

Probably the most significant solution was to bring the catenary and auxiliary catenary wires to the same level when passing in under the tunnel, as shown in *Figure 272*. The contact was still supported from the auxiliary catenary as normal, with the catenary off to the side.

Figure 272 also shows the inclusion of specially developed fibreglass arms to position the wires and register their radial loads. These arms were no doubt necessary because of insufficient space for installing the normal post type insulators for contact and auxiliary

catenary / catenary against the tunnel wall, while having suitable clearances to passing pantographs. An alternative would be to cut out pockets in the tunnel lining, but this can be extremely expensive and also destabilising to the tunnel itself. I think the fibreglass arms in the photo were used for consistency inside tunnels, even though they're installed on the remote side and not attached to the tunnel lining.

Note the single contact splice fitting installed close to the pull-off arm in this Figure, likely needed due to excessive pantograph arcing damage over time.

Further information for the Compound OHW System is provided in *Section 4.1.2*.

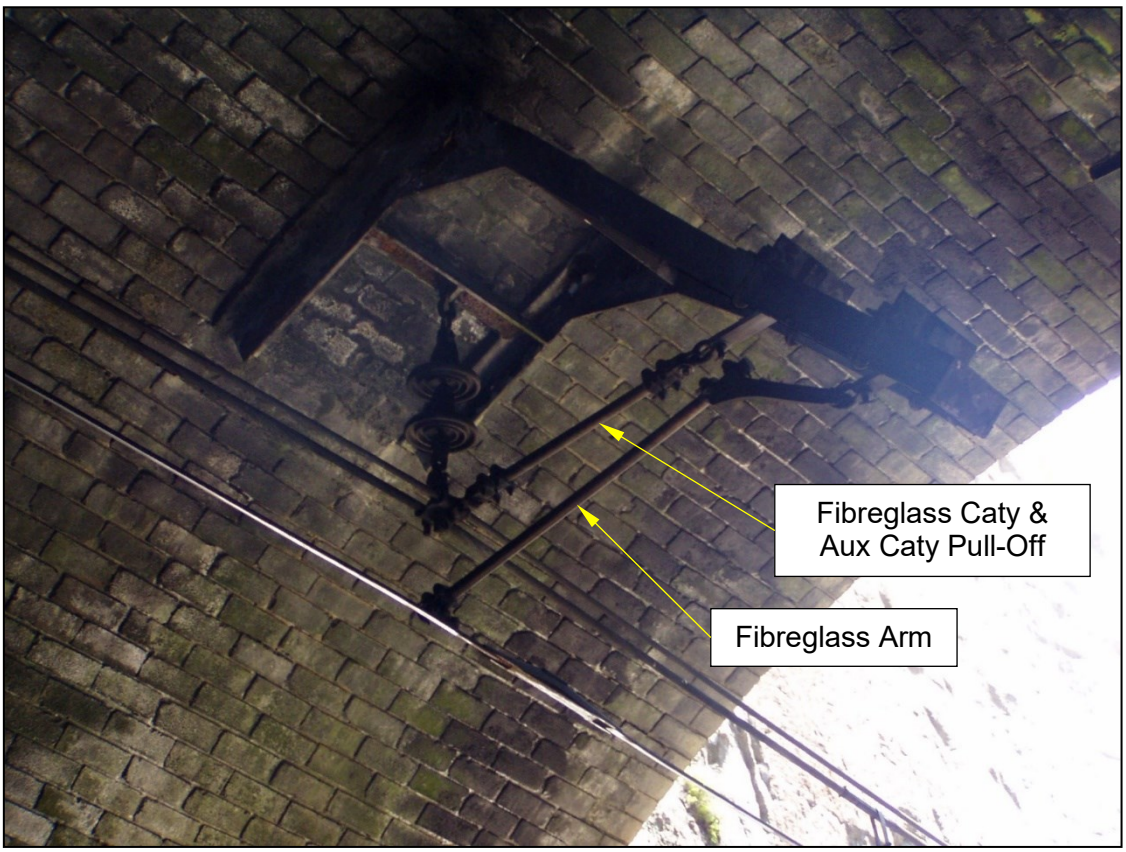


Figure 272 - Compound OHW support in tunnel using fibreglass Arm

REGULATED OHW ARRANGEMENTS

The main challenge for installing regulated OHW inside long tunnels, is to find suitable places for installing the tension regulators. The standard regulated OHW system requires 2 weight stacks, each of considerable size, to tension the catenary and twin contact wires.

A common approach is to install the regulators outside both ends of the tunnel (provided the length of tunnel allows this).

Example:

> For North Sydney Tunnels, the upgrade project around 2010 required the new OHW to be regulated. The various single-track and twin-track tunnels (housing the 4 sets of parallel tracks) were quite long, but short enough to still allow us to install weight tension regulators outside both ends in the open, and with a fixed mid-point anchor located inside about half way. The 1.5km to almost 2km wire run distances were also acceptable because most of the trackwork was relatively straight, meaning any tension deviation was kept within the required limits.

Although alternative tensioners to the standard weight stack are available elsewhere –

including modern gas tensioners and spring tensioners – they still require some significant space be made available in the normally restricted confines of a tunnel. Also, I understand that their tension lengths can be quite limited, thus needing many more devices (and more tension lengths) to be employed in long tunnels. But it's the huge tensions of the OHW – 30kN and 25kN for catenary and contact respectively – that may impede this approach.

For Sydney, various configurations exist for supporting & registering regulated OHW, and the most common of these are described below.

Coalcliff Tunnel Cantilever

In about 1987, the Illawarra Electrification Project from Waterfall to Port Kembla required the OHW to pass inside the tight confines of the Coalcliff Tunnel. This tunnel is somewhat "egg" shaped rather than the more common and broader "breadloaf" shaped tunnel, so there's even less space to install OHW support equipment. Refer to *Figure 273*. The tunnel is also quite long – about 1km.

Because of the heavy load to be drawn by the electric freight trains that were in operation back then, the OHW system was determined to require 2 sets of 270mm² catenary / 193mm² contact systems, installed side-by-side and separated by about 300mm, i.e. 2x270 / 2x193. This remains a unique OHW system for Sydney.

Some special support & registration arrangements were developed for allowing regulated OHW to be held in place within this tunnel – see *Figure 273* which gives a rough idea of their form (although they do tend to blend in with the brickwork background).

With these arrangements, the twin catenaries were supported from a swivel attachment positioned beneath a post type insulator, and this insulator swivelled from a pivoting arm attached to the tunnel lining. The pivoting arm had some limited adjustability to get the correct catenary height. Where contact pull-off arms were needed, they were insulated arms made from 25mm fibreglass rod with a "Raychem" brand heat-shrink skirt added to further increase the leakage path distance (fittings 246/14 – 21).

Figure 273 - Coalcliff Tunnel & one of the Regulated Support arrangements

Figure 274 shows a little more clearly a tunnel cantilever of the style first used in Coalcliff Tunnel (above), but this time located close to Kiama in an extremely tight tunnel (and installed much later in 2001). Note the separate catenary support and contact registration arrangements, displaced about 1 or 2m longitudinally away from each other. To gain additional clearance space, special pockets were cut out of the brickwork (to mount the hardware later) and the surface was then covered with "shotcrete".

Refer also to *Section 4.2.7* for more details on this tunnel.

Figure 274 - Tunnel Cantilever inside tunnel near Kiama

Mark-1 Tunnel Cantilever

Figure 275 shows the initial Mk-1 tunnel cantilever, which had an adjustable crank with many holes aligned vertically for a large amount of heel height adjustment. Unfortunately, that sometimes brought the pantograph very close to its lower end when arms were in the upper holes (as seen in this figure), unless long arms were installed to gain additional lateral clearance. This aspect could pose a rather nasty trap for the unwary.

Figure 275 - Initial Mark-1 Tunnel Cantilever

The multitude of vertical holes was modified later for the Goulburn St to Redfern Upgrade Project at Cleveland St overline bridge, as seen in *Figure 276*. Here some of the lower holes were trimmed off leaving only 3, and this resulted in greater clearance to pantographs, which reduced the chance of a clash (especially if long arms weren't used).

Figure 276 - Revised Mark-1 Tunnel Cantilever

The light frame of the early Mark-1 tunnel cantilever had some benefits, but lacked the general adjustability of

the later Mark-2 and Mark-3 arrangements.

The Mark-1 tunnel cantilever was employed at several other locations throughout the network until about 2004 (when the Mark-2 tunnel cantilever took its place).

Figure 277 shows the installation of new wire supported by the new tunnel cantilevers. Note the existing old L-iron and associated fittings on the face of the bridge for the previous fixed-anchored OHW. Of course, these were later removed.

Figure 277 - OHW being installed on Mk-1 TC

Mark-2 Tunnel Cantilever

The Mark-2 tunnel cantilever was developed in 2003 and signed off for use in 2004. Refer to *Figure 278* for a simplified design drawing of the arrangement.

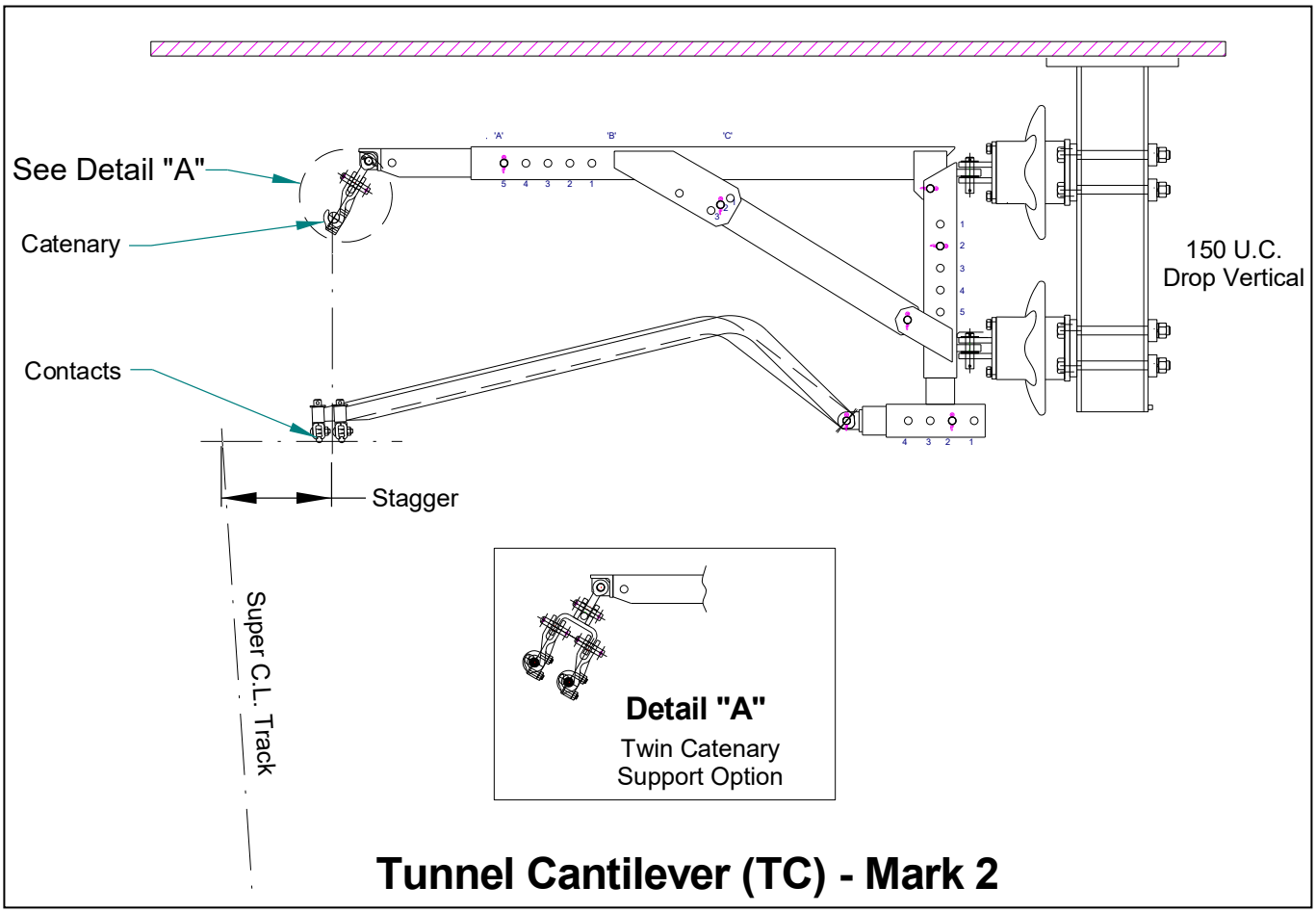


Figure 278 - Mk-2 Tunnel Cantilever developed for Chatswood Transport Interchange

The need for this arrangement came about because of the complicated trackwork that was planned for the "RES" (Railway Enclosed Structure – a flat ceiling "tunnel") at Chatswood, where the existing 2 North Shore tracks were to become 4 tracks – the outer 2 were for the

North Shore and the inner 2 were for the new tunnel link to Epping. Importantly, this new track configuration was to be inter-connected with 5 crossovers, all within a space of 200m within the RES. Refer to *Figure 280*.

The support for the OHW thus needed to provide a greater "reach", over the main line to register wires for the crossover tracks. The task was made more complicated by the restriction placed on us that limited the location of any new support beam locations from the roof of the tunnel.

Figure 279 - Mk-2 Tunnel Cantilever (being checked for correct Stagger)

Figure 280 - Mk-2 Tunnel Cantilevers installed at Chatswood "RES"

As well as providing the additional reach, the Mk-2 tunnel cantilevers were also designed to provide convenient adjustability to a number of parameters, and it did this without the need for any longer or shorter parts (other than pull-off arms). For instance, the top horizontal member is a telescoping tube arrangement, with 3 holes on the outer tube and 5 holes on the inner tube. This provided a huge 700mm of adjustability in 50mm increments and giving the necessary extended reach to a remote track if needed (within reason).

In situations where there is no contact radial load and with limited blowout, the Mk-2 tunnel cantilever has provision for the total removal of the lower pull-off arrangement. This includes its vertical/horizontal tube and pull-off inner tube, as well as the pull-off arm/s.

What's left is an arrangement that simply supports the weight of the OHW system. Refer to the right side support cantilever in *Figure 281*. Of course, the blowout for the extended contact bay (now 2 bays) must still be limited to the maximum ±381mm figure.

The use of telescoping tubes enabled the tunnel cantilever to be retracted and folded into a compact unit for transport to site.

Figure 281 - Tunnel Cantilevers (with & without a Pull-Off)

Figure 282 shows a situation at Epping (the then new concourse) where the OHW has twin catenaries and twin contacts, which makes it highly loaded. A special bracket is used to support and space the 2 catenaries from the single support hole, as detailed also in *Figure 278*.

Figure 283 shows a situation at North Sydney Tunnels where the tunnel cantilevers are installed back-to-back on a common 150UC drop vertical.

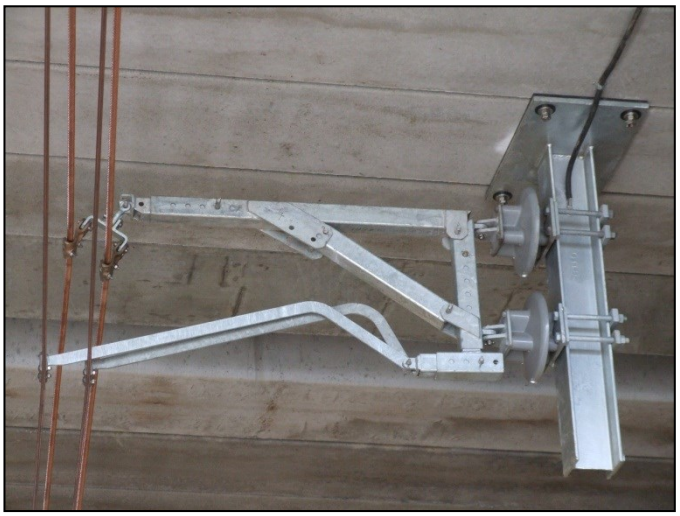


Figure 282 - Mk-2 Tunnel Cantilever supporting Twin Catenary OHW system

For comprehensive details of the Mark-2 tunnel cantilever, including its design, development and installation notes, refer to another of my documents, "The Mark-2 OHW Tunnel Cantilever", dated 19/2/2014.

Figure 283 - Back-To-Back Tunnel Cantilevers at North Sydney

Mark-3 Tunnel Cantilever

This is a relatively recent addition to the support & registration family (signed-off in 2012).

It is suitable for supporting regulated single or twin contacts with single or twin catenary OHW systems.

It has been specifically designed to suit the very limited headroom of the single track "breadloaf" shaped tunnels at North Sydney, although it could be used elsewhere in similar circumstances.

Note that there are strict design conditions on its use, including:

- For regulated OHW only.
- To be located within 500m of a fixed mid-point arrangement. This is due to the necessarily limited horizontal swing radius which can lead to a significant change of stagger at temperature extremes, as described in *Section 3.2.0.5*, *Stagger Change with Regulated Contact Wire*.
- For limited radial load (Type 1 or Type 2 maximum), due to the *short arms* and the need for a relatively *large heel height* to gain suitable pantograph clearance.
- No contact "ramp rate" (change of contact height in the adjacent bays).

The development of this arrangement came about because the alternative was to cut deep "pockets" into the tunnel lining for mounting the post type insulator. These pockets were needed to gain suitable clearances from the heel of the pull-off arms (of the normal shape used inside tunnels) vertically down to passing pantographs below. Cutting these pockets was going to prove extremely difficult and expensive. Because of the uncertainties of what lay behind the tunnel lining, the "pocket" approach also had significant risks.

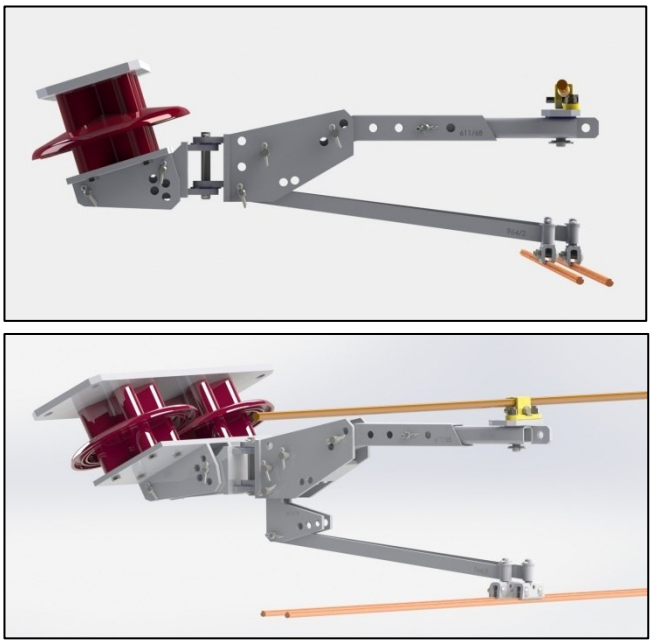


Figure 284 - 3-D Cad View of Mk-3 Tunnel Cantilever (lower view has optional Heel Adjuster)

This tunnel cantilever relies on determining the cross-sectional shape of the tunnel in each instance (through survey). This is needed so that the arrangement can be drawn on CAD for determining appropriate anchor bolt locations (into tunnel lining), and also to confirm what adjustment holes are to be selected for a suitable configuration at that location.

This tunnel cantilever has a reasonably high level of incremental adjustability, which was provided to help ensure that some adjustments could be made during installation (for whatever reason). The adjustment increments are provided by the 16mm stainless steel pins installed in discrete holes, normally providing 50mm increments (horizontal or vertical).

Figure 285 - Mk-3 Tunnel Cantilever installed at North Sydney in 2013

Figure 285 is a photo taken in a single-track tunnel during the commissioning of the Tunnel Cantilever. (Note that the pantograph horns are not correctly set – I think it's a pantograph specifically used for OHW construction.)

Figure 286 - Mk-3 Tunnel Cantilever in its most compact form

For much more detail on the Mark-3 tunnel cantilever, including its design, development and installation notes, refer to another of my documents, "The New Mark-3 OHW Tunnel Cantilever", dated 23/8/2013.

For more details on the Mark-2 and Mark-3 Tunnel Cantilevers as employed at North Sydney Tunnels, refer to *Section 4.2.8*.

3.2.6.5 Design Notes

A Desirable Tunnel OHW System

It is my opinion (only) that a highly desirable OHW system for use in long tunnels would be a simple *fixed-anchored* system and with *165mm² catenaries* and *twin 137mm² contact wires*. The number of catenaries – be it 1, 2 or even 3 – would be determined by the results of a load flow study of train loading (amps) and electrical resistance (for DCCB protection) aspects.

Such a system of matched conductor sizes forces all of the several wires in parallel to work as hard as each other (a very efficient outcome in terms of Amps per mm² of copper). It would then be likely that all conductors would reach maximum temperature *together* (instead of one wire reaching this temperature first and thus limiting the potential performance of the others).

Importantly, this F/A system would lend itself to a simple catenary support and contact registration arrangement using the usual compact insulators, in what is normally the tight confines of a tunnel. There would be no need for the more complicated S&R tunnel cantilevers of a regulated system (which needs to necessarily provide for longitudinal wire movement with temperature, and likely require more maintenance over its life).

The tension lengths can also be very long, and not be restricted by the pull-off movement limitations of a regulated tunnel cantilever (at temperature extremes). There would also be no need for special tension regulators within the tunnels, installed at very frequent intervals.

In addition (and in any case), with no cross-winds in single-track tunnels, it may be possible (with Standards approval) to increase the contact stagger to 350mm (say) or even greater, so as to obtain a more even wear pattern on the pantograph carbon strips (which I understand is a big and ongoing problem).

Although it's an old approach, the *simplicity* of the fixed-anchored system, when installed inside a tunnel, has proven itself to provide for extremely reliable train operations.

Mid-Bay Catenary Clearances

Because of the usual tight clearances inside a tunnel, the catenary can be located only about 150mm to 200mm clear of the lining at its support location. This is normally OK, but on the inside of a tight curve the sagged catenary can come close to the tunnel lining at mid-bay, and the electrical clearance here needs to be checked out at the tightest wire tension giving least mid-bay sag (i.e. at the coldest temperature if fixed-anchored).

During the design of the twin-track Airport OHW, this subtle issue had to be checked out and was deemed OK, but it was a definite concern at an early stage because of the curvature of the wall, the small tunnel clearances and the proposed tight horizontal track (and tunnel) curves.

Comparison of Compact Designs

Figure 287 compares the relative sizes of the Mk-3 (left side) versus the Mk-2 (right side) Tunnel Cantilevers.

The extremely tight space with the Mk-3 arrangement means that there are many more restrictions on its use – refer to its standard arrangement drawing and document write-up.

Heel Height

Any situation relying on a large amount of heel height (typically > 100mm) can only tolerate a relatively small radial load (+ wind load if applicable). This was discussed in *Section 3.2.0.5, Heel Height*.

The problem is that, if there's too much radial load, then the *large heel height* may cause the

contact height to increase from what was designed and expected. If this happens, then there's not a lot of contact weight to push down against the next passing pantograph, and this can lead to an excessive amount of pantograph uplift, more than anticipated. And if it's inside a tunnel with curved walls, this can lead to reduced clearance issues with the edge of the (now raised) pantograph. This includes reduced clearances to S&R equipment.

The culprit here is the *large heel height*. It's one of the situations where designers can inadvertently cause big problems to system reliability without knowing it.

LIGHTNING PROTECTION

It is fortunate that the OHW inside tunnels is protected against direct lightning strikes.

However, if lightning strikes the OHW outside the tunnel, half the lightning impulse current can travel on the OHW conductors into the tunnel. In this case, the accompanying lightning surge voltage may be sufficient to cause flashover anywhere there is inadequate clearance from the live OHW S&R equipment to earth (tunnel lining). Also, the large surge current (albeit for short duration) can cause some subsequent damage to the S&R equipment.

The various tunnel S&R arrangements commonly employ a single post type insulator for catenary support and another for contact registration. In some cases (e.g. the various Tunnel Cantilevers), 2 post type insulators spaced a distance apart support common steelwork that then holds and registers both catenary and contact wires.

The standard post type insulator enforces a 155mm distance from live to earth, and even though this distance is normally suitable for extinguishing an arc, it may not be sufficient distance to prevent a lightning discharge from initiating such an arc in the first place.

The risk of lightning travelling into a tunnel can be minimised by installing a surge arrester connected to the OHW just outside the tunnel. This can happen as a matter of course if a switch or feeding arrangement using 1500V cables is located nearby, as the cables should have surge arresters protecting them in any case (to clamp the voltage across the cable insulation and to divert some of the lightning current to earth).

One factor that may help prevent a lightning strike onto the OHW is if there are nearby preferential "targets" such as tall buildings and structures, and even the OHW support structures can help as they are higher than the catenary wire.

But lightning is a weird and wonderful (read unpredictable) thing, and it can sometimes strike in the most unlikely places. Refer to *Section 3.9* for more on lightning.

3.2.6.6 Status (c. 2014)

Fixed-anchored OHW remains a viable and reliable option inside long tunnels, and the relatively simple support & registration arrangements are quite suited to this application, provided they (and the bays of OHW) are properly designed.

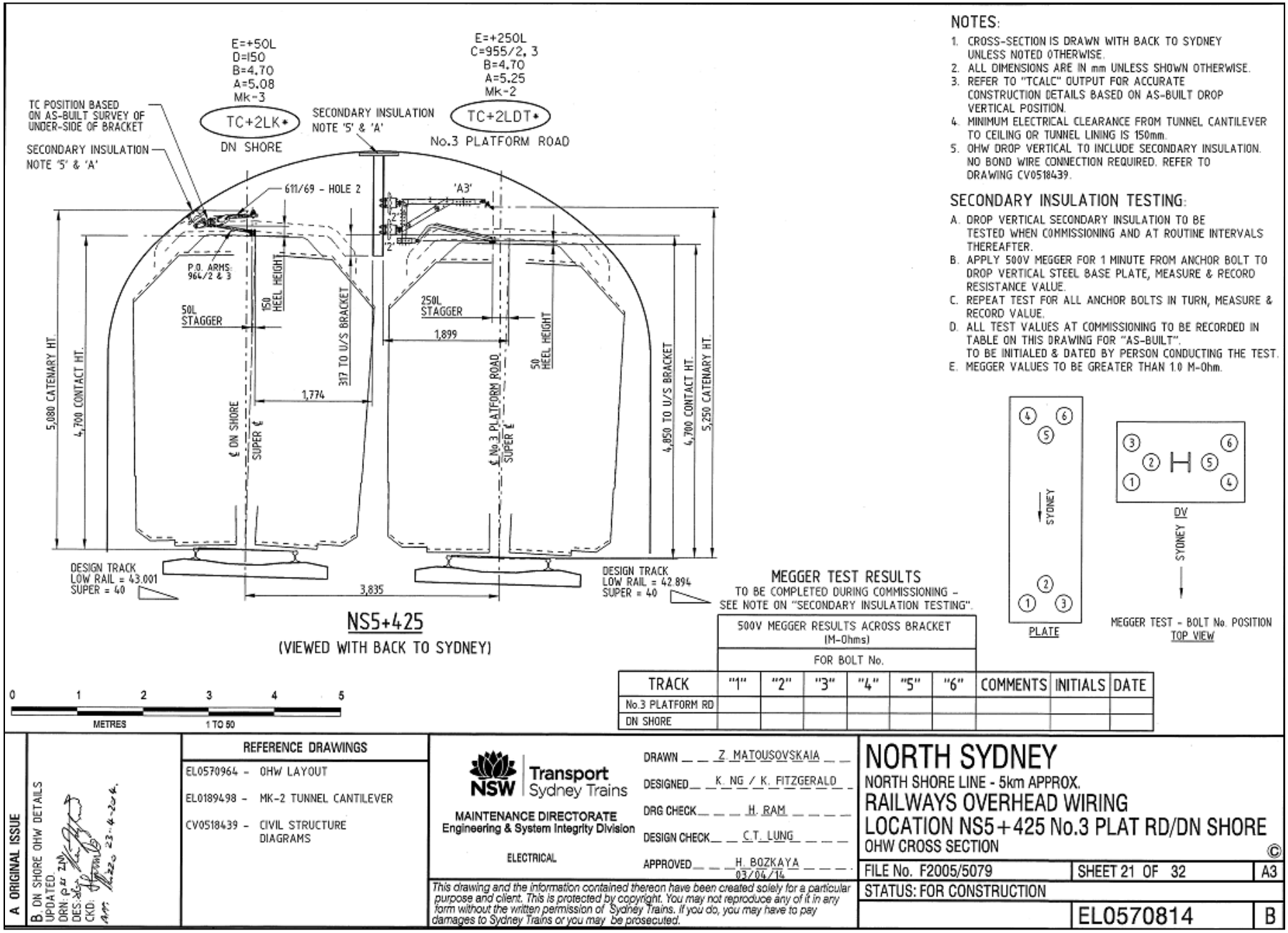
Installing regulated OHW through tunnels is a preferred option if suitable locations can be found for installing tension regulators. The Mark-2 and Mark-3 tunnel cantilevers may be appropriate in these circumstances.

3.2.6.7 Reference

Refer to *Table 20* (regulated S&R) and *Table 21* (fixed-anchored S&R) for relevant drawings.

For a comprehensive description of the Mark-2 tunnel Cantilever, refer to my document "The Mark-2 OHW Tunnel Cantilever", dated 19/2/2014.

For further information on the Mark-3 tunnel Cantilever, refer to my document "The New Mark-3 OHW Tunnel Cantilever", dated 23/8/2013.



NOTES:

1. CROSS-SECTION IS DRAWN WITH BACK TO SYDNEY UNLESS NOTED OTHERWISE.
2. ALL DIMENSIONS ARE IN mm UNLESS SHOWN OTHERWISE.
3. REFER TO "TCALC" OUTPUT FOR ACCURATE CONSTRUCTION DETAILS BASED ON AS-BUILT DROP VERTICAL POSITION.
4. MINIMUM ELECTRICAL CLEARANCE FROM TUNNEL CANTILEVER TO CEILING OR TUNNEL LINING IS 150mm.
5. OHW DROP VERTICAL TO INCLUDE SECONDARY INSULATION. NO BOND WIRE CONNECTION REQUIRED. REFER TO DRAWING CV0518439.

SECONDARY INSULATION TESTING:

A. DROP VERTICAL SECONDARY INSULATION TO BE TESTED WHEN COMMISSIONING AND AT ROUTINE INTERVALS THEREAFTER.
B. APPLY 500V MEGGER FOR 1 MINUTE FROM ANCHOR BOLT TO DROP VERTICAL STEEL BASE PLATE, MEASURE & RECORD RESISTANCE VALUE.
C. REPEAT TEST FOR ALL ANCHOR BOLTS IN TURN, MEASURE & RECORD VALUE.
D. ALL TEST VALUES AT COMMISSIONING TO BE RECORDED IN TABLE ON THIS DRAWING FOR "AS-BUILT". TO BE INITIALED & DATED BY PERSON CONDUCTING THE TEST.
E. MEGGER VALUES TO BE GREATER THAN 1.0 M-Ohm.

PLATE

MEGGER TEST - BOLT No. POSITION TOP VIEW

MEGGER TEST RESULTS

TO BE COMPLETED DURING COMMISSIONING - SEE NOTE ON "SECONDARY INSULATION TESTING".

	500V MEGGER RESULTS ACROSS BRACKET (M-Ohms) FOR BOLT No.								
TRACK	"1"	"2"	"3"	"4"	"5"	"6"	COMMENTS	INITIALS	DATE
No.3 PLATFORM RD									
DN SHORE									

A ORIGINAL ISSUE
B. DN SHORE OHW DETAILS UPDATED. DRN: pz 23-4-14. DES: KF 23-4-14. CKD: AM 23-4-14.

REFERENCE DRAWINGS

EL0570964 - OHW LAYOUT
EL0189498 - MK-2 TUNNEL CANTILEVER
CV0518439 - CIVIL STRUCTURE DIAGRAMS

NSW Transport Sydney Trains
MAINTENANCE DIRECTORATE
Engineering & System Integrity Division
ELECTRICAL

DRAWN Z. MATOUSOVSKAIA
DESIGNED K. NG / K. FITZGERALD
DRG CHECK H. RAM
DESIGN CHECK C.T. LUNG
APPROVED H. BOZKAYA 03/04/14

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NORTH SYDNEY
NORTH SHORE LINE - 5km APPROX.
RAILWAYS OVERHEAD WIRING
LOCATION NS5+425 No.3 PLAT RD/DN SHORE
OHW CROSS SECTION ©

FILE No. F2005/5079	SHEET 21 OF 32	A3
STATUS: FOR CONSTRUCTION		
	EL0570814	B

Figure 287 - Cross-Section of Mk-3 (left) & Mk-2 (right) Tunnel Cantilevers at North Sydney

3.2.7 Auxiliary Feeder Arrangements

3.2.7.1 Description

This simple steel bracket arrangement holds up the auxiliary feeder (A/F) wire that "electrically strengthens" the OHW run.

It's often in the shape of a single support "gallows" as shown in *Figure 288*, and should include 1 or 2 support insulators for primary insulation.

Alternatively the A/F support can come from something as simple as a steel plate outrigged from the post type insulator supporting the main catenary wire, as shown later in *Figure 291*.

The A/F wire itself is normally located close to the main OHW conductors being paralleled.

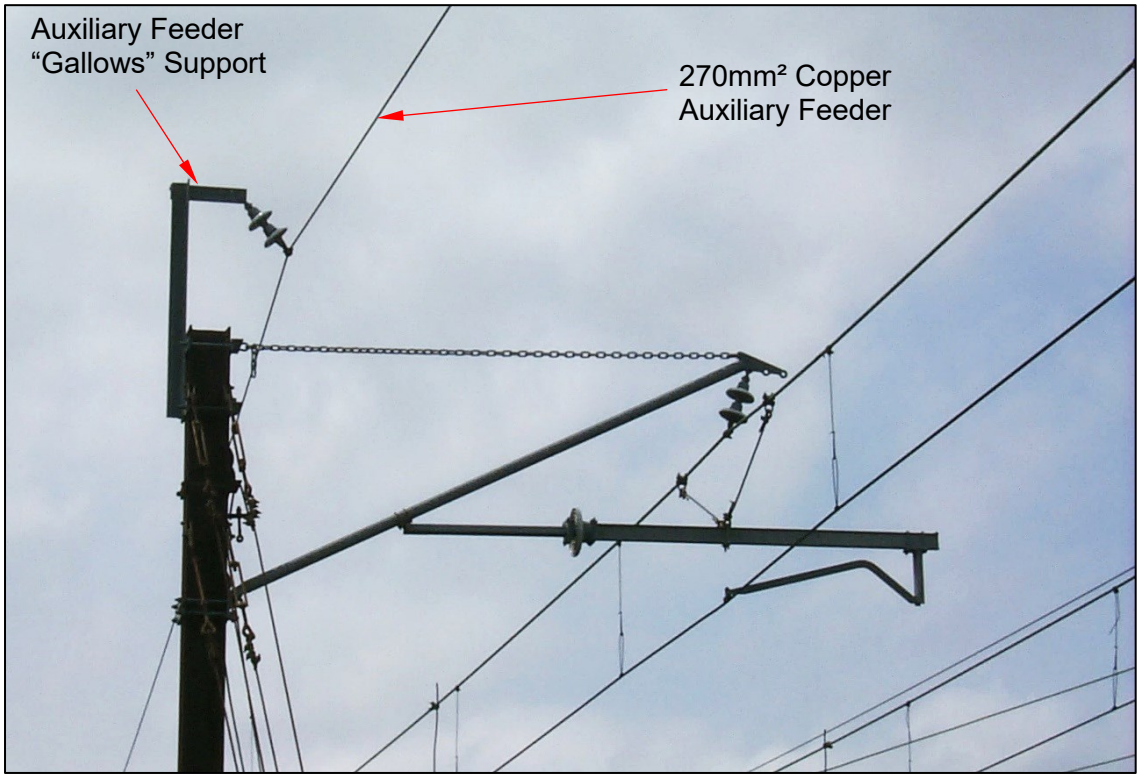


Figure 288 - Example of an Auxiliary Feeder supported near the top of a Mast

3.2.7.2 Function

An auxiliary feeder support holds the weight and radial loads of the A/F wire.

In certain situations, it can also provide a definite horizontal separation between the A/F wire and its associated main catenary wire, which can be useful. For example, *Figure 291* separates these wires by 216mm at the support.

3.2.7.3 Typical Components

Working from the live side to dead, typical components include:

- *Steel support bracket* – for positioning the auxiliary feeder at a particular height and/or offset from the track. This bracket is installed on the dead side, typically on an independently installed single-leg gallows fitting made from channel steel (named so for obvious reasons). Or it could take the form of a simple catenary suspension bracket when installed under a portal bridge.

- *Support Insulator* – this usually consists of a pair of 190mm diameter suspension insulators in series. Alternatively, and especially inside tunnels, it can comprise a single independent post type insulator.
- *Connecting Plate* – this steel plate is located on the live side, usually connected directly to the insulator. It can be a flat plate for connecting a butterfly clamp as seen in *Figure 291*. Or it can be a twin suspension steel link fitting to take a catenary suspension clamp as shown in *Figure 292*.
- *Conductor Clamp* – this clamp holds the A/F wire. It can take the form of a normal catenary suspension clamp (when supported from twin suspension insulators), or a butterfly clamp installed from a flat steel plate (when a post type insulator is employed).

3.2.7.4 Configuration

Typically, the configuration takes one of the following forms:

- A/F conductor independently *suspended* under a portal bridge. See *Figure 289*.
- A/F conductor suspended from a special *gallows* fitting. See *Figure 290*.
- A/F conductor supported next to the catenary wire from a common post type insulator. See *Figure 291*.
- A/F conductor supported next to the catenary wire from a common string of suspension insulators and special *link plate*. Refer to *Figure 292*.

Figure 289 - Auxiliary Feeder suspended under Portal bridge

One benefit of the gallows fitting is that it can raise and/or shift the position of the auxiliary feeder wire laterally to meet certain clearance requirements.

If the catenary is suspended from twin suspension insulators, then a special "twin suspension link" fitting can co-locate catenary and A/F wires from these insulators, giving a lateral wire spacing of about 90mm or 150mm (depending on which link fitting is used).

The last configuration minimises parts, since the insulator is already there supporting the catenary wire, and all that's needed is an extension plate and another catenary clamp. (The horizontal distance between catenary and A/F is then typically 216mm.)

Figure 290 - Auxiliary Feeder installed on Gallows fitting

3.2.7.5 Design Notes

LOCATION

The auxiliary feeder wire should be located close to the OHW being electrically strengthened, and so its support needs to also be located nearby.

There needs to be no doubt that the conductors belong together and are of the same electrical section.

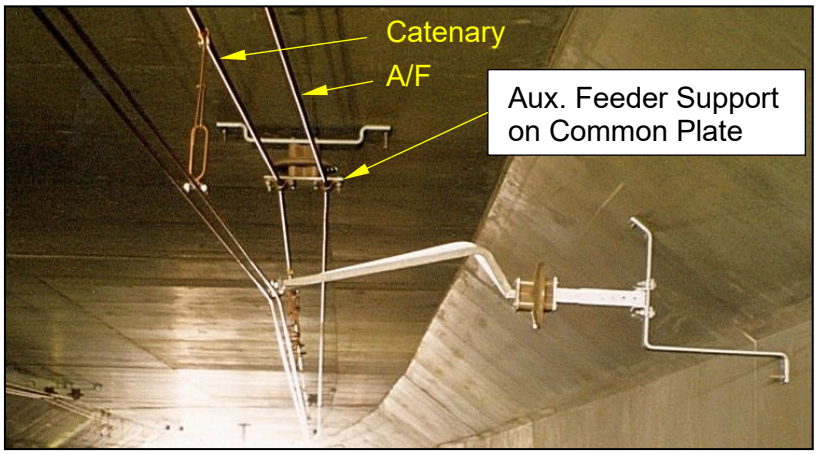


Figure 291 - Auxiliary Feeder installed from common Catenary support bracket (Airport Line)

See also *Section 3.1.0.5*, *Auxiliary Feeders* and *Section 3.1.1.5*, *Location of Auxiliary Feeders*.

TWIN SUSPENSION LINK PLATE ARRANGEMENT

An auxiliary feeder can be installed next to the main catenary wire by using a twin suspension link and additional suspension clamp to connect the A/F wire. This same twin link configuration is used in cantilevers that support the regulated twin catenary OHW systems.

This is a simple arrangement, and can save on the cost of additional insulators, but it can lead to a rather cranked outcome. This is due to unbalanced weight and radial loads of catenary versus the auxiliary feeder wire located next to it.

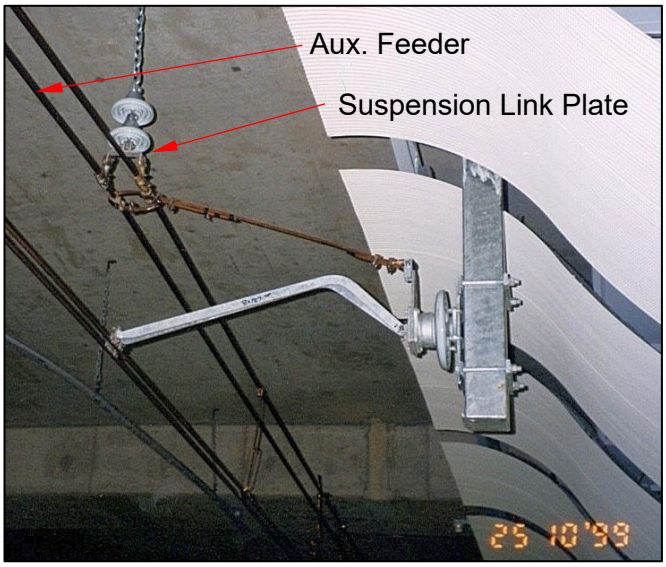


Figure 292 - Aux. Feeder on Twin Suspension Link Plate (Airport Line)

Refer to *Figure 292* for one such instance of this arrangement. Here, the aux. feeder is to the left of the main catenary wire supporting twin contacts. A span wire connects to the catenary and a wire loop then connects to the A/F to hold both radial loads.

MECHANICAL LOADING

Note that certain *gallows fittings* have also been used to help thread *aerial feeders* from switches (for instance) to a remote section of OHW, and they can also take the mechanical strain off the switch. So, they do have other uses (not just for supporting auxiliary feeders). This application can be seen further on in *Figure 444* and *Figure 448*.

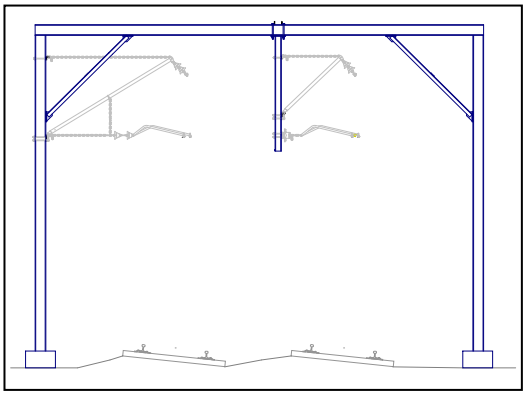
3.2.7.6 Status (c. 2014)

All auxiliary feeder supports detailed above are still relevant for certain OHW systems.

3.2.7.7 Reference

Refer to *Table 20* and *Table 21* in *Section 3.2* for relevant drawings.

3.3 SUPPORT STRUCTURES



3.3.0 General

> *Note:*
> An excellent reference on Sydney's OHW support structures is RailCorp Engineering Manual TMC-331, "Design of Overhead Wiring Structures & Signal Gantries", which was put together by Paul Honor in 2011. This covers the description and design details of all the (then) current OHW structures, including anchors. And is/was an excellent detailed reference when designing OHW structures for Sydney's OHW system.

The following information in this section of the document gives relatively simple details of the support structures *from an OHW designer's perspective only*.

3.3.0.1 Description

OHW support structures appear as steel "masts" or steel "portals". A portal may include one or more "drop verticals" (DVs). In the past "wood poles" have also been used to support OHW, although now they tend to be reserved for emergencies only (due to their easier & quicker installation as a temporarily structure).

The legs of these structures are normally erected about 3m laterally clear from the centre of an adjacent track. This gives good passing clearance for the train kinematic envelope, whilst allowing suitable support & registration equipment to be installed for attaching the OHW. Being mostly installed between tracks, drop verticals are situated about 2m from the track/s.

3.3.0.2 Function

Support structures provide the following functions:

- They provide a suitable vertical and/or horizontal *platform* on which to mount the OHW support & registration arrangement/s.
- They are sized *tall* enough to provide appropriate OHW conductor heights in each bay.
- They are *strong* enough to support the OHW weight, radial and wind loads, which are transferred back to the structure via the installed support & registration arrangements (described in *Section 3.2*).
- The support they offer resists additional deflection with wind loading, i.e. they are required to be relatively *stiff* so as to not sway so much as to adversely affect contact stagger (and ultimately pantograph security) under windy conditions.
- They can usually be *placed* exactly where the OHW designer needs them – both longitudinally and laterally – to support the OHW in the wire run.

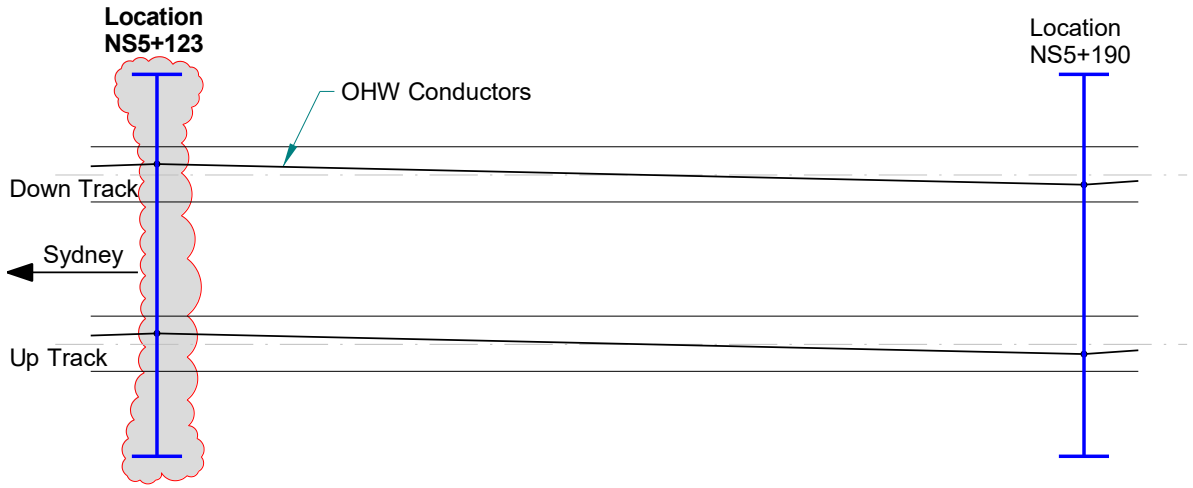
The OHW support structures, and their relation to the bay of OHW, are diagrammatically shown in *Figure 293* – in this case a portal structure with a mid-track drop vertical.

OHW Support Structures

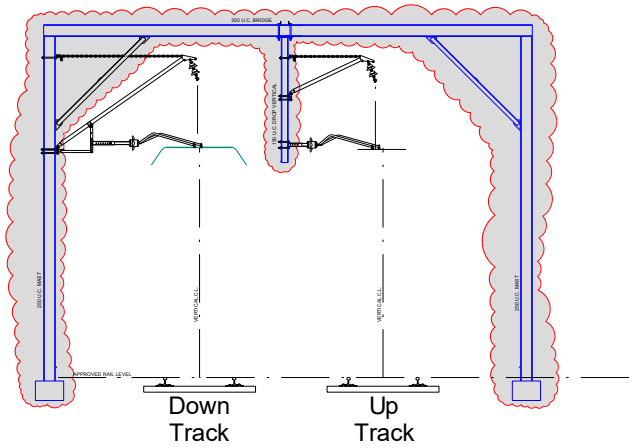
OHW Support Structures

Asset
NS5+123, Down Track

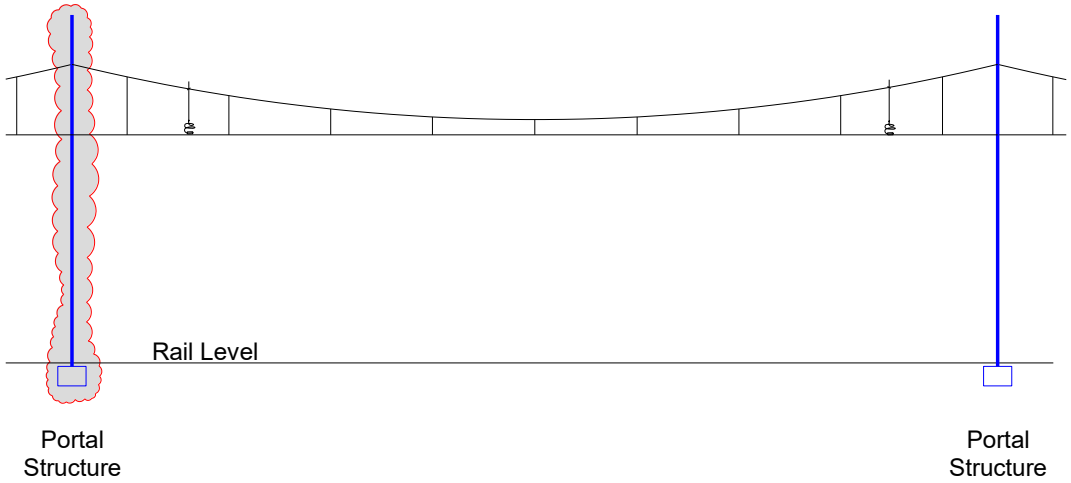
Includes ... Wood Pole
Steel Mast
Steel Portal & Drop Verticals



Top View



Left End View



Front View

Figure 293 - OHW Support Structures - boundary

3.3.0.3 Typical Components

Referring to *Figure 294*, the following major components are common to most support structures:

- A *vertical structure*. This can be a steel mast or portal leg, or a wooden pole (installed directly in the ground).
- A *concrete foundation* installed in the ground. A steel mast or portal leg can be directly planted in the ground and encased in concrete. However more commonly these days, a steel reinforced concrete cage can be formed below ground, and the structure can be bolted to its top "pedestal" (located just above ground level to reduce corrosion).
- A horizontal steel *bridge* (at times referred to as a "boom") is sometimes needed. In the case of a portal, it spans over tracks between the tops of a pair of portal legs. In the case of a special "Way &Works cantilever" (which is like a half-portal), it connects to a single leg only. These horizontal steel sections usually require one or more "knee-braces", installed from leg to bridge at 45° to the bridge, to help stiffen the structure.
- On a portal, one or more *drop verticals* may be installed at nominated distances along the portal bridge, for supporting the OHW above the track being serviced. Drop verticals can also be installed from the W&W cantilever structure, forming what is known as a "W&W cantilever & nose" – the nose being the drop vertical at the end of the bridge.

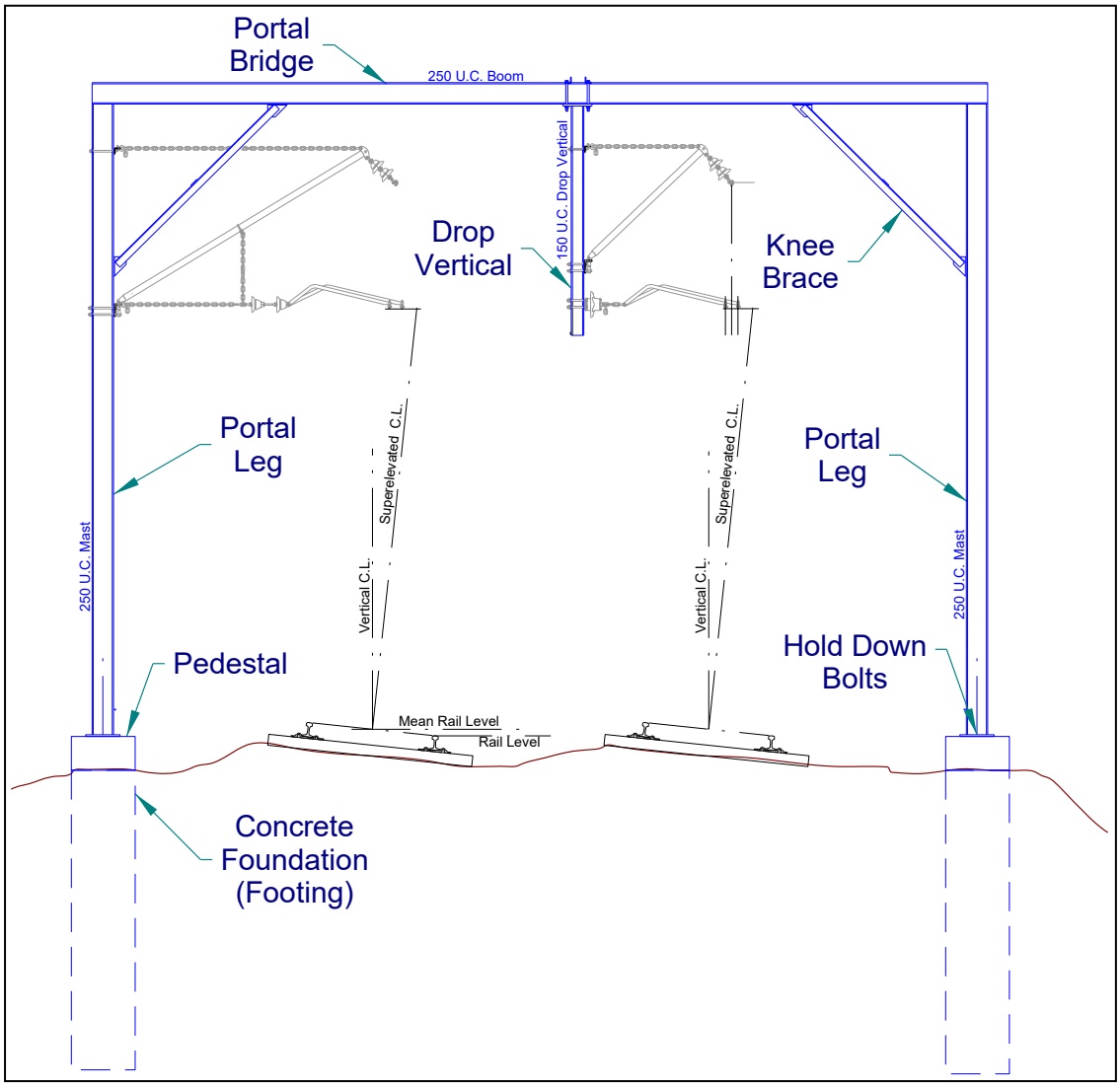


Figure 294 - Typical components of a Support Structure

Note:

"W&W" = Way & Works (or Ways & Works?). This was the term used a long time ago for the track and associated civil infrastructure. The NSW Government Railway engineering group – the Way & Works Branch – managed this infrastructure. (The OHW was managed by the Electrical Branch.) I think around 1989 it split up to become the Track and Civil disciplines (respectively). The track is referred to as the "Permanent Way".

So the "W&W Cantilever & Nose" could be called a "Civil Cantilever & Nose" structure these days, or even simply "Cantilever & Nose".

Figure 295 shows 3 types of common OHW structures:

- A *cantilever & nose* in the foreground, then
- A *mast* (with back-to-back OHW cantilevers), and then
- A *portal* located further back.

Figure 295 - Several types of OHW Structures

3.3.0.4 Configuration

OHW support structures are normally one of the following:

- *Steel mast* – designed, supplied and installed by Civil staff.
- *Steel portal* (with associated *drop verticals*) – designed, supplied and installed by Civil staff.
- *Wood pole* – usually designed, supplied and installed by Electrical staff. These are generally no longer used, except for emergency situations requiring a quick and temporary alternative support for OHW, to get trains running again.

Note that for many years, even though they seemed to hold certain distinct advantages, *concrete poles* were (and probably still are) *unacceptable* in Sydney's OHW system. See *Section 3.3.0.5, Concrete Poles are Unacceptable*.

A drop vertical (DV) can comprise either a ***Single*** section of vertical steel ("DSV") or ***Twin*** verticals spaced about 1m longitudinally apart ("DTV"). Early drop verticals included a diagonal brace that connected the back of drop vertical to the portal bridge, offering significant rigidity to it (the "DR" style drop verticals).

Each of the above major structure types are covered in the following subsections.

Steel structures can be made from a few different steel sections (cross-sectional shapes). They mostly include:

- Universal Column (UC)
- Square Hollow Sections (SHS)
- Universal Beam (UB) – this is an I-Beam. Here, the depth of "web" of the Universal Beam is significantly longer than its outer "flange".

Support structures can mount OHW *support & registration arrangements* in the following configurations:

- Installed on one side of the vertical support structure (which is normal).
- Installed in a *back-to-back* fashion, providing support for two adjacent tracks (the support structure is located in between the tracks). Note that this configuration can be installed on masts, portal legs and also drop verticals.
- One support structure can be configured to mount 2 sets of OHW conductors located side-by-side over the same track (with appropriate twin support brackets), as can be needed in an overlap. See *left* view of *Figure 296*.
  Note: this approach has been used in the past mainly to provide a cheaper arrangement on a common structure. However, it was awkward to install correctly and is no longer recommended. Instead, a twin drop vertical should be installed as described below (and which provides a more robust solution).
- In the case of a portal spanning a number of tracks, one or more drop verticals can be used to support the OHW.

  - A ***single drop vertical*** (DSV) can be installed between nominated tracks so that the OHW for the required track can be supported & registered. In addition, back-to-back support arrangements can hold 2 sets of OHW as described above.
  - A ***twin drop vertical*** (DTV) can be used to support 2 sets of OHW loads, such as required for overlaps (for in-running and adjacent out-of-running wires), or when wiring a crossover track (with one taking main line OHW and the other taking the crossover OHW). See *right* view of *Figure 296*. With twin DVs, up to 4 sets of OHW can be handled by employing back-to-back configurations on each DV (although the worst-case load imbalance needs to be checked out).

Figure 296 - Cantilevers on Twin Brackets (left) versus Twin DVs (right)

The structure's overall dimensions are usually dictated by the following.

- *Vertically* – the mast height is dictated by the height of the OHW catenary wires to be supported. The current standard 6.5m catenary height requires the mast height or height to underside of portal bridge to be 7.5m above the highest track being serviced. This then provides about 500mm for the catenary suspension insulators, and an additional 500mm for adjustments should they be needed in the future, e.g. with unanticipated track lifts.
- *Horizontally* – in the case of a multi-track portal, the distance between the 2 legs is governed by the overall distance between the outside tracks being serviced, plus a clearance of about 3m between each outside track and structure leg.

The structure size (i.e. width of mast or portal leg & bridge) is normally dictated by the bending moment on the structure, which is generated by the OHW equipment and various other loads. These loads include OHW conductor weight, radial loads (at the tightest conductor tensions) and wind loads, and the weight of a section insulator installed in an adjacent bay, or the weight of a person on the OHW, etc. Wind loading onto the support structure itself is also taken into account by Civil Design.

The structure size is determined about half way through the OHW design process, when relatively accurate loadings can be predicted with some degree of confidence.

Wherever practical, a standard mast or portal structure size is preferred – the usual size for Sydney is 250 UC (250mm x 250mm Universal Column section). However, there are other standard steel sections used for making OHW structures, including double channels (DCs) with regular welded battens spacing 2 channels apart, and square hollow sections (SHS). Note that there are several grades (thicknesses) of steel section available for each steel size, and a thicker grade of steel can usually provide additional strength if required.

Quite often, the OHW support structure will also *anchor* some of the OHW conductors, so the additional anchor loads will need to be addressed in the design of the structure.

The types of OHW support structures and their relevant TMC codes are listed in *Table 25*, although this may no longer be relevant as the design and subsequent maintenance of these structures (apart from wood poles) is handled by the Civil section.

TMP Code	Equipment Name
EP-08-16-00-00	**OHW Support Structure**
EP-08-16-01-00	*Wood Pole*
EP-08-16-11-00	*Steel Mast*
EP-08-16-31-00	*Steel Portal (including Drop Verticals)*

Table 25 - OHW Support Structures

3.3.0.5 Design Notes

Below are some notes from an OHW designer's perspective. However, apart from wood poles, the design of such structures is performed by civil/structural engineers and consequently there are many aspects that are outside the scope of this document. In which case, please refer to RailCorp Engineering Manual TMC-331, "Design of Overhead Wiring Structures & Signal Gantries".

STEEL STRUCTURES

Steel is the preferred material for support structures, as it exhibits the following desirable characteristics:

- Steel has high strength and resistance to deformation.
- It can be conveniently manufactured in suitable lengths and cross-sections.
- Steel is a homogeneous material, so its strength behaviour throughout its length can be predicted with confidence (and its use can be designed accordingly).
- It's readily available in Sydney (Australia has vast amounts of iron ore and used to have a thriving steel production capability nearby at Newcastle and Wollongong).
- It provides a proven and relatively inexpensive support solution over its lifetime (measured in many decades).

The main disadvantage with steel is that it needs to be appropriately protected from corrosion. All new steel support structures used for OHW support are *hot-dip galvanised*, which provides a relatively thick coating of zinc on the entire surface. This extends the life of the steelwork by at least 20 or 30 years or more (depending on the local environment).

Older steel structures were often painted. This offered limited protection before the paint deteriorated and corrosion set in. Note that the subsequent corrosion was mostly surface corrosion which was slow at degrading the steel surface, but areas of accelerated corrosion could occur where moisture was allowed to collect, and is particularly active near the sea.

There are certain locations where recent OHW structures were galvanised and then painted as well. These areas were influenced by heritage or aesthetic values, and include:

- *Sydney Harbour Bridge*. New OHW structures to replace the existing ones were to take on the same steel "lattice" form and painted "Sydney Harbour Bridge Grey" (installed around 2010) – see *Figure 326* further on.
- *Goulburn St Viaduct near Central*. Again, most of the structures were to mimic the existing steel lattice form, and painted a dark grey (installed in the early 2000s) – see *Figure 302*.
- *Dapto to Kiama*. This project (in the early 2000s) required the steel structures to be painted "Cobalt Blue" whenever they were within 1km of water (what's that you say?). This requirement often makes people wonder why the structures abruptly change from the usual silver/grey galvanised look to being blue. (I tend to think it's a decent blue though, and it blends in well with the environment, although it's now quite faded.) For instance, see *Figure 66* further back, and *Figure 319* a bit further on.

STRUCTURE SETOUT

The design of any new OHW requires that the proposed location of OHW structures (to support & register the OHW) be set out in the field. This can help people understand where they are intended to be placed so that any objections can be raised before things go too far – this is part of the "All Parties Walkthrough" process, which can take place a number of times during various stages of a project.

To *locate* a proposed new structure in the field, there were and are several approaches, including the following.

- The old method of showing the proposed location of new structures was to mark their track chainage in white crayon on the vertical web of an adjacent track rail. (The convention was to mark on the outer face of the down rail of the down track where this was possible and practical.) The new structure/s were laterally offset from the various tracks at that location, according to the design drawings.
  The "Chainage" location measurement used to be marked here (in feet), and this was eventually replaced by marking in metres.
  The location number represents an *approximate distance* from Sydney's Central Station.
  The old imperial measurement system used a "+" sign to separate the hundreds of feet, e.g. SW123+45 (in feet). When the metric system came along, the "+" sign replaced the decimal point in kilometres, e.g. SW1+234 (approx. 1.234km).
  This method of using the "+" sign was included to distinguish it from a more accurate track chainage (or later track kilometrage). The "+" sign was (and remains) an important distinguisher, to avoid confusion. However … See *Section 5.3.3* for more information on this aspect (which has an unfortunate element to it now, as described in this reference).
- If new structures are to be located close to existing structures, then a longitudinal offset from any existing structure could be conveniently used. E.g. New structure is 3m on Sydney side of existing structure N123+456.
- The current method requires the exact centreline *Eastings & Northings* of the proposed new OHW locations to be worked out on CAD, and subsequently surveyed & marked (pegged out) in the field, for far more accurate results. This is by far the best approach, and is relatively easy to achieve, but likely requires additional survey work.

COMMON STRUCTURE SECTIONS & SIZES

The maximum bending moment on a mast or portal leg normally occurs at the bottom of the structure, which is typically at (or near) ground, and OHW structures need to be *strong* enough to cope with this bending moment.

The structures must also be *stiff* enough to prevent excessive static *deflection* of the structure, as well as *change in deflection* with wind loading, in order to provide appropriate "serviceability" for the OHW system. The *change in deflection* can momentarily affect the contact staggers, which may jeopardise pantograph security unless properly controlled.

So, these 2 aspects are referred to as the "strength & serviceability criteria".

Various steel sections are used, and a number of different configurations of the sections are also available to provide the necessary strength and stiffness, while aiming to keep the structure dimensions within reason (due to aesthetic concerns, etc.).

Universal Column (UC)

These days most masts and portals use a "universal column" (UC) section of steel (sometimes referred to, rightly or wrongly, as an I-beam). Refer to *Figure 297*.

The standard mast sizes used are 200mm, 250mm and 310mm (the actual physical size can be a little different from these numbers). There are different *gauges* – thicknesses of steel – for

each size, and the same size mast can be made stronger if the gauge is made thicker. Various gauges have been standardised for Sydney's system.

A smaller size of 150mm UC is used predominantly for drop verticals these days. Earlier drop verticals used 200UC and even 250UC, but the 150UC size has been optimised for most situations. See *Figure 298* for various sizes.

Note:

Apparently, the Dapto to Kiama Electrification Project in the early 2000s used a smaller non-standard 150mm size for masts (previously 200UC was deemed the smallest practical size). Concern was raised at the time, that although this size mast structure might be strong enough for the loads, it may not be *stiff* enough, especially if strong winds caused some dynamic wire oscillation which may then resonate and make the OHW unserviceable for running a reliable train service (any change in deflection with wind affects the contact stagger). So far, this serviceability issue has not been a problem, but independent civil calculation checks at the time were apparently borderline, so it probably should be something to keep an eye on, and especially if and when rust sets in.

The UC section is incredibly strong in bending across its length, when one flange is in tension and the other is in compression. Its *web* does not contribute much to the strength, and is normally kept thin for this reason (so the weight is less). It is much less strong in bending if the section is rotated 90°.

The UC shape is hopeless in torsion, and any such loads need to be carefully checked out during the Civil design process. (The longitudinal conductor movement in a regulated OHW system, when registering high radial loads, can sometimes cause certain S&R equipment to generate torsional loads on the support structure – refer to *Section 3.2.1.5*, *A Compressive Load Problem*, and particularly *Figure 220*.)

One benefit to this UC shape is that all its surfaces are exposed, so it can be easily checked for corrosion (most of the time).

Another big benefit for OHW is the ability to attach brackets to the flanges using cleats. "Lindapters" are a brand of cleat that are common in the construction industry, and their "B20L" cleat type is commonly used in OHW construction. See *Section 5.1.20.2*, *Cleat Connection* for more information on cleats.

Cleating is particularly handy in back-to-back scenarios, such as 2 cantilevers installed on a common drop vertical. This is because the mounting brackets are installed on independent flanges of the drop vertical. This situation can be seen back in *Figure 283*. The alternative wrap-around brackets would likely impede the correct cantilever configuration of one of the two cantilevers. (Both back-to-back brackets would either need to be at the same height or at completely different heights to avoid fouling.)

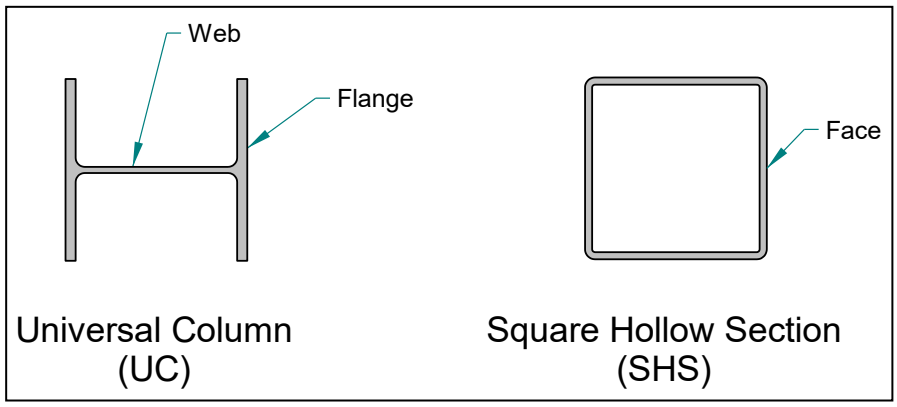


Figure 297 - Common Steel Sections for Masts & Portal Legs

150	200	250	300
150 UC	200 UC	250 UC	310 UC
150 SHS	200 SHS	250 SHS	300 SHS

Figure 298 - Typical steel sizes & sections for OHW Structures

Square Hollow Section (SHS)

Over recent years the square hollow section has become more popular for use as masts and portals (legs, bridges and even drop verticals). This is probably because of the lowering costs of this steel section over the years (and probably driven by popularity), the novel ways of connecting it to other parts, and its overall strength. There have also been projects that have demanded its use over the UC section for aesthetic reasons, e.g. drop verticals used at all stations on the Airport Line. Refer to *Figure 297* which shows the cross-sectional shape.

The square hollow section shape is strong in tension, compression, bending and torsion, and all this comes without adding too much weight.

One slight down side is that any OHW brackets installed onto the structure can only be clamped *around* the section – it does not allow for the cleating option (across a flange) that's available on a UC section. However, this is only a relatively minor problem that can usually be worked around.

Sometimes holes can be drilled into one of the faces of the SHS to attach equipment. To this end, special "Hollo-Bolts" are sometimes used to help in this regard.

The outer surface of this shape can be readily checked for corrosion (in the majority of cases).

However, the SHS inner surfaces are hidden and so special care is needed when designing the structure, to try to lessen the chance of water entering, and being trapped in internal areas where corrosion can take hold and not be noticed. If water does get in, there should be holes or other provisions for adequately draining any such water, to help prevent accelerated corrosion. *Figure 299* shows how water had been trapped inside the SHS leg of a portal structure, and only discovered when someone drilled out the pop rivet fasteners, presumably to reinstall track control marker plaques.

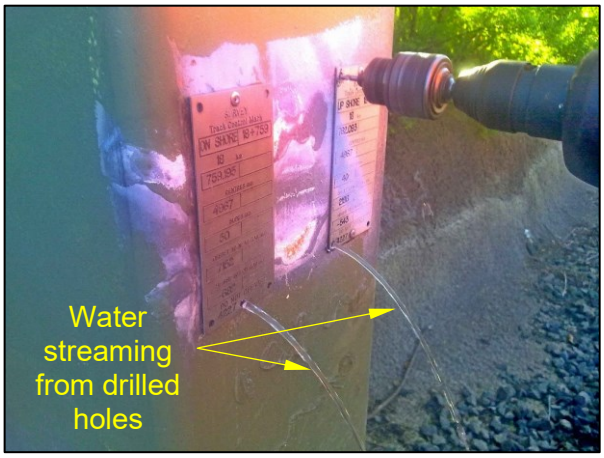


Figure 299 - Water trapped inside a Portal leg (SHS)

Corrosion can be detected by the presence of brown stains against a galvanised or painted surface, and this is one good reason for keeping the grey (or some colour other than brown) protective coating in good condition on the structure.

Double Channel (DC)

Double channel structures are common throughout the network.

They are mostly used when spanning more than 2 tracks, or where the structure is otherwise heavily loaded, including feeder structures (with walkways and/or multiple copper cable feeders installed).

As the name implies, 2 channel sections are used as the main structural elements, and they are separated with regularly spaced welded battens along the structure length. The large spacing between channels helps improve the overall strength and stiffness. Refer to *Figure 300*. Note that the channels usually face *inwards* for portal legs and *outwards* for portal bridges.

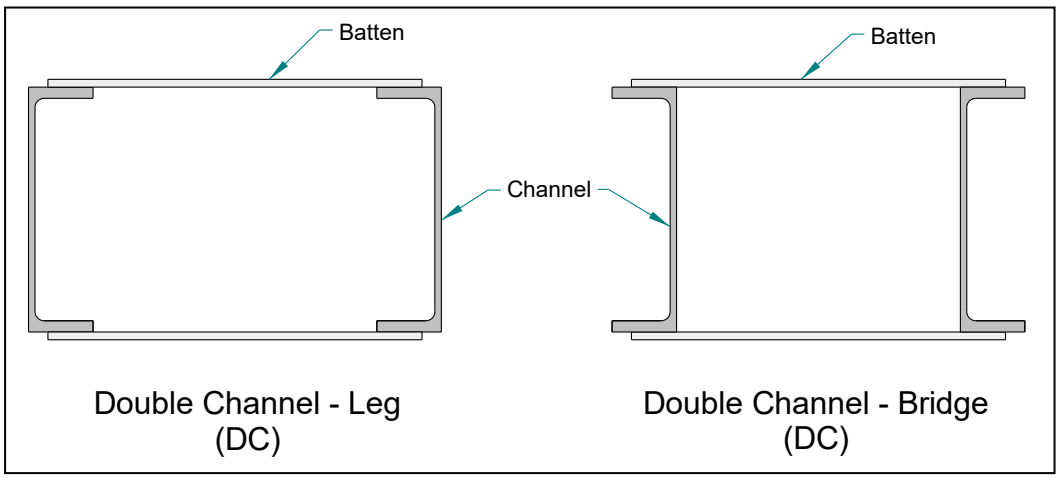


Figure 300 - Alternate steel configuration for Portal legs & bridges

One down side to this configuration is that the battens can be used as climbing aids on portal legs. However, access can be prevented using "access prevention grilles" if required.

Another down side is the fabrication. The battens need to be welded into place, which adds costs.

Also, these batten areas can be more difficult and tedious to access to arrest any corrosion if it takes place later on.

Figure 301 - Double-Channel Portal Structure (Strathfield)

Double Universal Beam (DUB)

I understand these hefty structures are even stronger than a double channel section, so they seem to be reserved for heavily loaded situations.

OHW Structure Size

Q. Why are Sydney's OHW Structures so large in comparison to other overseas electric traction systems?

This has been a common question from overseas rail visitors at various times in the past, and probably still happens from time to time even now.

Some have said it's "gold plating", and unfortunately the stigma from this sort of comment tends to stick, especially at sensitive high levels of the organisation and government, and particularly when coming from supposed overseas "experts".

The structures are likely to be a similar overall size as elsewhere (especially their heights above track), but Sydney's structures are probably constructed with *bigger sections* and *thicker steel*. Note that a steel section size can come in 2 to 4 different thicknesses of steel in their webs (and flanges), offering different levels of strength (and weight) for that same overall section size, e.g. 310 U.C. comes in 4 variants: 97, 118, 137 and 158 kg/m.

Where overseas they might get away with a slender 150 Universal Column (UC) section size masts, we would probably require 250 UC masts, and likewise with portal structures. Why?

And why not use some lighter "Lattice" type structures, similar to that shown further on in *Figure 318*.

I've tried to simplify and describe the rationale of determining structure size (as I understand it) in the below 2-page summary – *Table 26*.

Why do Sydney's OHW Structures seem to be so large, compared to other overseas OHW systems?

Reason	Details
1. Train energy demands are large. These energy demands on the electrical network are due to:	
➢ Heavy trains (even more so these days due to recent crash worthiness requirements).	The heavier mass of the trains requires more electric power to accelerate them. This means increased current is demanded from the OHW.
➢ The fleet is mostly 8 or 10 car double deck trains, which are able to transport thousands of people per train (crush loaded), making them heavier.	See above. According to official RailCorp documents, the recently acquired 8-car "Waratah" double deck trains have the capacity to transport 2,150 people, plus 16 people in wheelchairs. This is a huge amount of overall weight to transfer around the rail system.
➢ Timetabling improvements means more frequent train services.	E.g. 1 train every 3 minutes instead of 1 every 10 mins. The OHW needs time to cool before next train heats it up again.
➢ There are some significantly long and steep grades in Sydney, which the trains have to climb at reasonable speed. To maintain even a reasonable speed up the steep gradients requires a huge amount of power (current), and consumes an enormous amount of energy. Examples shown on right …	***Central …*** ➢ Southern approach to the Sydney Harbour Bridge (Track Grade is as low as 1 in 30). ***North …*** ➢ Epping to Pennant Hills (Track Grades as low as 1 in 40 – *Figure 675*). ➢ Hawkesbury River to Cowan (Track Grade is mostly 1 in 40). ***West …*** ➢ Valley Heights to Katoomba (Track Grade as low as 1 in 31). ***Illawarra …*** ➢ Como to Sutherland (Track Grade as low as 1 in 40).
➢ Most of the fleet is now air-conditioned.	Sydney has a temperate climate, and people now demand air-conditioned comfort while travelling. Also, the windows on most trains now do not open (for safety reasons, etc.), and there is no natural ventilation from outside, relying instead on air-conditioning. The extra power for the air-conditioning load means more current is demanded from the OHW.
➢ Modern trains draw huge accelerating current and for longer times, to rapidly get to speed and reduce travel times.	As I understand it, this is due to modern electronic circuits driving three phase motors, which are capable of drawing more current and for longer periods, even if the supply voltage is lower. This has been a major concern when trying to look after various parts of the electrical infrastructure (not just the OHW).
➢ "Regenerative Braking", which attempts to pump energy back into the OHW to supply nearby trains (if they can take this excess energy).	This helps reduce the total energy consumption of the system, and helps reduce brake pad wear on each train. This also causes the transfer of more electrical current through the OHW (although the current flows in the reverse direction in this case). Whether current flows in one direction or the reverse, it all heats these OHW conductors up. The conductors need time to cool before the next train comes along, otherwise the OHW will overheat, *anneal* and become permanently damaged.

2. As a consequence, electrical currents in the 1500V OHW conductors can be huge. The large train energy requirements mean *electrical current* (amps) passing via the OHW catenary and contact wires to the trains *is much larger*.	This is at least in part due to the relatively small supply voltage of 1,500V compared with say 25,000V. Using the simple equation: Power = Voltage × Current [Watts = Volts × Amps], Smaller volts requires *larger current* to get same power, and it's the *current that heats the wires up*. [Heat = ƒ(Current ²)] Example: 2MW = 1,333 Amps @ 1,500V, or = 80 Amps @ 25kV (i.e. only 6% or 1,253A less!)
3. More current necessitates OHW copper wires to be bigger, and/or more of them are needed in parallel. The larger OHW electrical current requires catenary and contact *conductors to be bigger* (i.e. a larger amount of total copper cross-sectional area). They are *heavier* as a result. Large conductors are needed (or use more conductors in parallel). Otherwise they'll overheat & become permanently damaged (annealed).	***Catenary:*** 3 of the 4 main catenary sizes used in Sydney are all considered large by European standards. Only the 165mm² catenary is comparable. (cf. 270mm², 327mm² & 510mm² sizes). One only needs to look at supplier catalogues to see the relatively small conductor sizes on offer overseas. The current maximum catenary size for future Sydney OHW electrification is the 270mm². The current "standard" OHW system has 270mm² catenary with 2x137mm² contacts. ***Contact:*** Very few places use contact sizes greater than about 160mm², yet Sydney uses 193mm². Sydney has 2 contact wire sizes: 137mm² and 193mm². It seems no European OHW parts manufacturers stock anything greater than about 150mm². Even Sydney's 137mm² size seems large by European standards.
4. So, OHW tensions are larger. a) Thicker & heavier electrical conductors are required to have a *higher mechanical tension applied to them to keep them in the air* (with a suitably small sag profile in each bay). Alternatively, installing more conductors in parallel means more overall tension and applied loading.	Sydney's current standard regulated wire tensions are: *Catenary:* 165mm² → 18.1kN 270mm² → 30kN (for twin contacts) 327mm² → 26.4kN (not for future use) 510mm² → 34.6kN (not for future use) *Contact:* 2×137mm² → 2×12.5kN 193mm² → 18.0kN
b) More than the above, "*world's best practice*" dictates that these OHW conductors (both catenary & contact wires) are to be tensioned as tight as is practical for various benefits.	Tighter tensions produce superior dynamic interaction with the train's pantographs, allowing higher speeds, better current collection from the train's several pantographs, and other improvements. (Note that the tighter tensions can help increase the bay lengths and thereby reduce the number of OHW structures per km, which is also a good outcome.)
5. Therefore, the mechanical loads on OHW structures are bigger. The structures are *larger size* and with *thicker gauge steel* because the OHW *mechanical loadings placed on them are significantly bigger*. → **"LARGE" OHW Structures**	Sydney's simple vertical *masts* are normally 250 UC size, (instead of the smaller 200 or 150 UC size used elsewhere). Because Sydney had access to steelworks close by, the cost of steel was relatively cheap and so the structures could be made of larger standard sections, and not rely on the costly process of welded lattice structures (which might be lighter with less steel, but are likely also more expensive, particularly with their on-going maintenance, notably the close inspection – in areas that are difficult to access – for rust at the numerous welds and joints where water can pool). Likewise for *multi-track portals*.

Table 26 - Rationale for "large" OHW Structures in Sydney's OHW system

Figure 302 shows the portal member size difference for a recent upgrade project on the viaduct from Central to Goulburn St. Note that the painted *lattice* structures were a heritage requirement for this particular project.

The left structure is a (then new) galvanised & painted one, which is about to replace the old structure to its right.

The members of the left structure are larger and thicker, due to the additional mechanical loads of a modern regulated OHW system (which delivers the far superior current rating as necessitated by trains these days).

Figure 302 - New Structure with higher loads, replacing old

So in summary, the larger structure sizes are generally a consequence of the following.

- It's a *lower voltage* OHW system: 1,500V system, not 25kV (elsewhere).
- The lower voltage necessitates *much heavier current* to deliver similar on-board power. Long, steep upward track grades also demand a huge amount of power for long periods during the ascent. Air conditioning adds its current burden. And regenerative braking means the current flows for longer (both ways – to the train and also away from it).
- *Voltage drop* at the train, due to heavier current through resistance in OHW (and track rails) requires *even larger current* to deliver the same on-board power. ($P = V \times I$).
- Heavy current demands *larger copper conductor cross-sectional area* (otherwise the conductor will overheat and become permanently damaged).
- Large (heavy) conductors need *higher tensions* to keep them in the air, supported over a reasonable distance (of up to 73m bays). Also, the trend of "World's Best Practice" is to tighten the conductors as much as is practical (e.g. almost to the 3:1 safety factor in the catenary) to get vastly improved OHW dynamics, etc., especially with medium to higher speed trains.
- Common UC / SHS sections make structures *simpler, cheaper and easier to maintain*, instead of more complex fabricated/welded lattice structures (which may appear lighter).

⟶ *The need for OHW Structures to have larger and thicker steel sections.*

There may also be some differences brought about by progressive changes to the structure codes used for designing such structures (but this is beyond my understanding).

> Note that an independent *Value Engineering Study* was conducted in the 1990s with a number of key players and outside experts, to thoroughly understand this situation and try to find alternate ways to reduce the structure sizes if practical. This came at a time when much of the OHW system was about to be renewed and regulated. In essence, I understand the overall outcome actually endorsed the current approach to designing the OHW support structures for Sydney (consistent with the latest Australian Standards).

STRUCTURE HEIGHT

Over the years, the move to regulated OHW with its constant, tighter catenary tensions, has been accompanied by a general reduction in the height of OHW support structures, e.g. from the old portal heights of about 8.5m to track (as I recall), reduced down to 7.5m = 1m lower.

For the old fixed-anchored OHW the catenary height was normally quite high due to the deeper catenary sag at lower design tensions (hot temperatures), along with the longer bays adopted (up to 73m or so). This required tall portal structures, with the catenary attached to the underside of the portal bridge. Heights of 8m above track were common and even 8.5m or 9m could be seen around the network.

Note that the tall portals could be supplemented with shorter, simple PP masts within the bay, installed for pull-off locations that register the wires only (not support them). The pull-offs allow the extremely long bay lengths to be used (yielding longer virtual spans which helped control tension changes with temperature), ensuring pantograph security is achieved even around tight track curves.

The fixed-anchored situation contrasts with the current standard portal heights of 7.5m for a regulated system. Indeed, for the most part this could probably be reduced to a standard 7m height if required. (For example, due to aesthetic reasons the new portals installed at Waverton Station around 2007 had a reduced height of 7m to minimise the visual impact with distant view of Sydney skyline and the Sydney Harbour Bridge.) But it's prudent to have some extra height just in case things change in time, so 7.5m was settled on as the standard.

The standard 7.5m height above track allows for:

- the standard regulated catenary height of 6.5m, plus
- about 60mm or so for half the track superelevation (on tight track curves),
- about 450mm for the suspension insulators when vertical (no radial load), plus
- about 150m for the cantilever "guitar head" fitting with horizontal chain back to the mast.

This tallies to 7.16m. The extra 340mm can allow for:

- a third suspension insulator of 150mm if required (e.g. for secondary insulation scheme),
- an amount for subsequent and unforeseen track lifts if ever needed.

Regulated systems can be installed on simple and inexpensive PP masts on straight and curved track down to about 800m radius, and only below this are portals required for the typical 2 track situation (i.e. for Type 3 radial loads). The need for the portal is so that a drop vertical can be situated *between* the tracks to mount a cantilever on, so as to support & register the OHW for this remote track. And it provides the all-important Independent Registration.

STRUCTURE LEG PLACEMENT

Most OHW structure legs are required to be located reasonably close to tracks, since it is the trains running on these tracks that the OHW can be servicing. However, the structures need to be installed well clear of the running traffic to avoid the possibility of collision. For instance, the train's *end throw* and *centre throw* distances should be taken into consideration when determining any reduced lateral clearances, and this is a function of horizontal track radius. (Refer to *Section 6.3.1.2* for more on these clearances.)

OHW masts and portal legs are typically located 3.2m from the centre of closest main line track to the centre of the structure leg. Where structures are located between tracks, this required the track centres at that location to be at least 6.4m.

If a mast or portal leg must be placed any closer to the adjacent tracks, then special "structure gauge" clearance calculations are needed to confirm suitable clearances. I think the base line is something like "Kinematic Envelope + 200mm" (KE + 200).

As I understand it, closer distances are acceptable in situations of slower speed traffic, such as in sidings. And there are existing tight situations where a structure can only be placed a limited distance away (such as on a viaduct), and clearance calculations can help in the argument for accepting the reduced clearances (for approval).

If there are no other impediments, then placing the majority of structures at 3.2m means there's usually no need for performing clearance calculations, which is good. And importantly, no questions are likely to be asked. (Keeping the structures well clear, where you can, is probably a matter of prudence.)

Refer to the various Civil and Track Standards for more information.

MAST RAKE & DEFLECTION

Masts usually support OHW on one side only, and in these cases they will be installed with "rake", which is a lean away from the track being serviced.

Because the unloaded mast is straight, the typical design value for rake is 17mm horizontal distance (taken over a standard 2,000mm vertical distance).

The purpose of rake is to try to make the final loaded mast appear close to vertical. Refer to *Figure 303*. This makes it not only more aesthetically pleasing to the eye, it also tends to suggest that the mast is handling the load well, especially over time.

There have been situations where some masts were installed vertically (rake = 0mm), or with negative rake (i.e. mast leaning towards the track), then later loaded heavily, causing people to wonder whether something was failing. For instance, was the mast slumping in the ground over time? And this query may arise many times over the life of the equipment, wasting so much time.

If the loaded mast ends up close to vertical or even leaning away from the load, this tends to suggest everything is fine, and no questions are asked, which is important when maintaining the asset over its life.

Rake can also be seen further back in *Figure 212*.

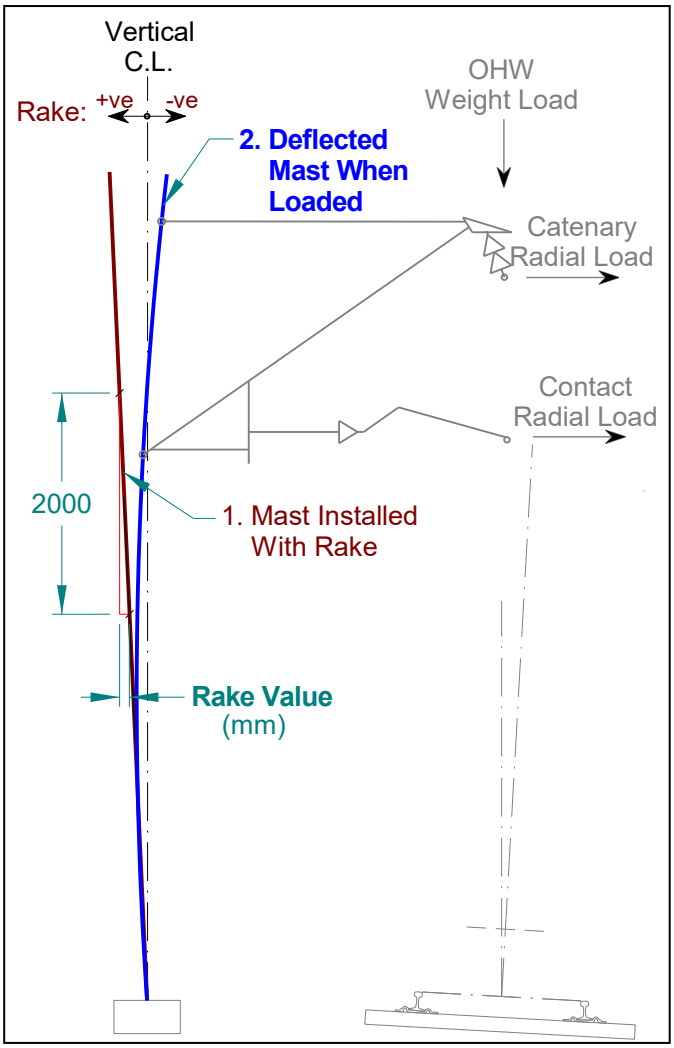


Figure 303 - Mast installed with Rake to counteract deflection

Figure 609 (much further on) is a photo of 2 masts with relatively high radial loads but in opposite directions, and the consequence on these slender masts (150 UCs ?) in terms of deflection can be readily seen.

FOOTING

The "footing" is the foundation of a mast or portal leg. This is a crucial part of the structure, as all mechanical loads are ultimately transferred into this area and to ground.

The easiest footing is provided by a mast inserted directly into a bored hole of suitable depth in the ground. The diameter of the hole is quite a bit larger than the inserted mast to allow concrete to be poured into it, which then provides additional stability (positively locking the mast into the ground socket) with less chance of the structure *slumping* over time.

Alternatively (and preferably), the foundation can be formed by digging a hole of suitable depth, inserting a steel reinforcing cage and then pouring concrete to form a block with a capping "pedestal" located above ground level (to avoid water pooling which can lead to corrosion problems later on, etc.).

Several vertical threaded rods normally protrude above the pedestal, for connecting to the base plate of the mast or portal leg. These are commonly known as "hold down bolts". Typically, there are 4 or 6 bolts, with 2 nuts required per bolt to securely fasten the steel base plate. (One of the nuts acts as a lock nut, and there is some conjecture as to whether the upper or lower nut position best performs this locking function.)

Grout is a fine cement mixture, and is sometimes used for packing in small spaces, including between mast base plates and pedestals. When dried, it helps to spread any applied mechanical load more uniformly to the pedestal and ground, and it can prevent rubbish from collecting in that space.

Sometimes other types of pads are sandwiched between base plate and pedestal, e.g. employing special plastic pads for electrical insulation of structure leg to ground (to minimise electrolysis corrosion, etc.).

A "HPM" mast provides a bottom base plate welded to the structure, with holes to connect it to corresponding mounting bolts in the foundation.

The pedestal approach can provide a better outcome in several ways. With care, the pedestal can be formed and left to set over weeks, then the mast can be quickly installed on it. This approach also enables any lean on the mast to be corrected, or a suitable rake applied.

APPEARANCE

To the trained eye of an OHW engineer, various OHW structures may appear a thing of beauty. However, to the eye of the general public, all OHW is probably considered as ugly and its visual impact should be kept to a minimum (it could be perceived as a necessary evil).

There are several things that can be done to *minimise its visual impact*, including:

a) Minimising the *number of structures*. This can be achieved by installing one (portal) structure holding several wire runs, rather than installing one structure per run. For example, installing a portal with twin drop verticals is likely to be less obtrusive than installing 2 portals 2 metres apart.
   Also maximising the spacing of structures (according to the Structure Spacing Chart for that OHW System) results in less structures per kilometre.

b) *Painting* the structure in sympathy with the surroundings. A good example here is the requirement to paint all structures from Argyle to North Sydney across the Sydney Harbour Bridge in "Sydney Harbour Bridge Grey". (A heritage requirement placed on the recent OHW Upgrade project.)

c) In multi-track situations, aim to have all discrete OHW structures *line up* across the track, so as to avoid a so-called "Picket Fence" outcome, and give the appearance of a properly designed layout (rather than some apparently haphazard placement). This can't always be

done (e.g. when servicing crossovers), but wherever practical, it should be done. Some standards actually call for this requirement to avoid picket fencing.

d) *Reduce the structure height* where the area is deemed visually sensitive.

See *Section 6.6*, *The Surroundings* for more on aesthetics.

I was once asked to come up with options and costs to remove one particular old portal structure from the view someone had from their newly-acquired house at Lavender Bay. This historic house had an otherwise unobstructed view of the western side of Sydney Harbour Bridge and the Sydney skyline up close.

Unfortunately, there's not a lot that could be done to get rid of the obstruction – the best that could be hoped for was to minimise the visual impact. For instance, if and when the OHW is renewed as a regulated system with lower conductor heights, the offending portal could be replaced by a single mast, of perhaps the smaller 200 SHS size, and painted in sympathy with the surroundings. (See the "Aside" in *Section 3.2.4.4* for more on this area.)

STRENGTH & SERVICEABILITY CRITERIA

It goes without saying that the support structures need to be ***strong*** enough to cope with all sorts of anticipated loading situations. Accurate loading diagrams are provided by OHW designers to Civil Design for the purpose of designing appropriate structures at each location.

Refer to *Figure 305*, which shows a sample Loading Diagram for one location inside the "Railway Enclosure Structure" (RES) at Chatswood, where 3 of the 7 runs of OHW that pass through are supported from Mk-2 Tunnel Cantilevers on drop verticals.

However, the other essential requirement of these structures is that of "serviceability" – the structures need to be ***rigid*** enough to prevent excessive deflection under static loading and especially under further wind loading.

The reason why this is important is that the contact wire stagger alignment is directly affected by any additional deflection of the structure supporting the pull-off registration equipment (e.g. cantilever).

Whilst the CCalc computer program can determine the deflection in a mast, and work out the constructional details of the required cantilever taking into account this amount of static deflection, it cannot (and should not) take into account the additional dynamic deflection due to wind loading (130km/h). This wind can act in all directions, and additional mast deflection can momentarily change the existing stagger (i.e. more or less stagger) which can have detrimental effects on pantograph security throughout adjacent bays. Refer to *Figure 304*.

For OHW work, we generally require the OHW structures to be limited to an additional deflection of ±50mm at the contact (pull-off) height. This means a 250mm stagger could, for short periods, increase to 300mm or decrease to 200mm under strong wind – but no more. But bear in mind that the wire where it's staggered is well controlled by the pull-off arm. It's at mid-bay of the previous or next bay that the alignment of the contact wire may be more in jeopardy.

Pantograph security is all-important to train service reliability. If too much mast deflection is encountered with wind, the shifted contact wire position may no longer be able to adequately control the pantograph, and in the extreme case, may allow it to rise up above the contact wire and damage the droppers and other OHW equipment for many hundreds of metres.

The overall *consequence* of this serviceability concern is that OHW structures might be:

- A little thicker gauge of the same steel size.
  For example, at the design stage a 250 U.C. @ 72.9kg/m (flange thickness of 14.2mm)

might be upgraded to 250U.C. @ 89.5kg/m (with flange thickness of 17.3mm). Alternatively,

- A physically larger structure size is called up.
  For example, a 250U.C. becomes a 310 U.C. structure (although this might then allow a lighter gauge steel in this larger UC steel size).

In practical terms, in the distant past I understand the designer would apply a 160km/h wind speed for designing the structure for *strength*, and would apply a 130km/h wind speed to check for *serviceability*. However, things are a lot more complicated now, with the OHW structures being designed using a "Limit State" approach, but the idea is there.

The guidelines for these decisions and any altered requirements are documented in RailCorp Civil Engineering Manual TMC 331, "Design of OHW Structures & Signal Gantries".

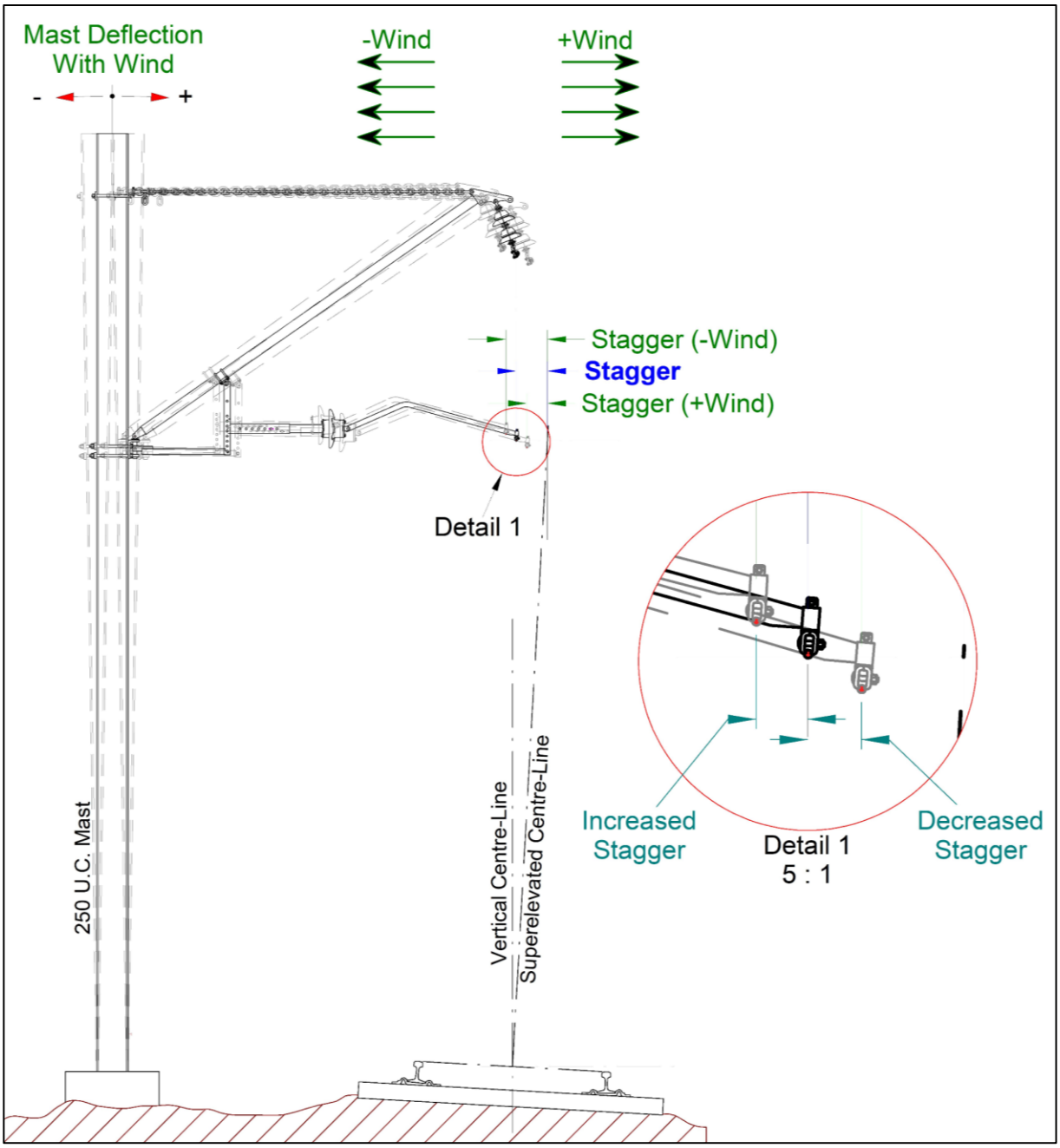


Figure 304 - Contact Stagger affected by Wind on Mast

OHW Combined Loading Diagram

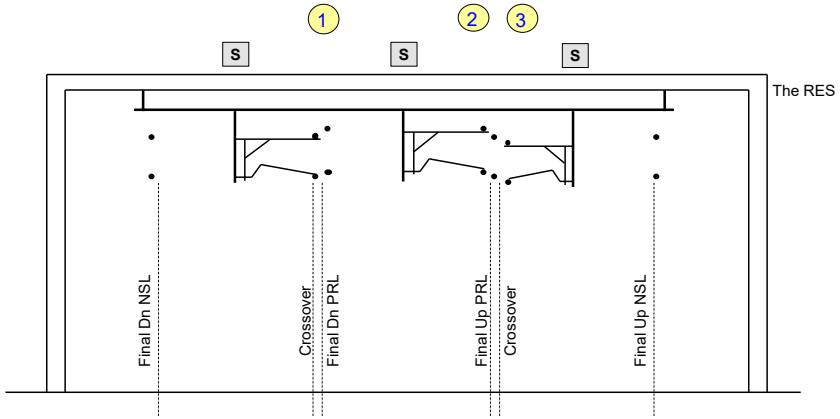
(Mark 1.5)

Project : PRL - CHATSWOOD INTERFACE

owner and maintainer of the nsw rail network
RAILINFRASTRUCTURE CORPORATION

Notes :

1. Catenary & Contact heights are typically +/-100mm.
2. Unless otherwise stated :
   - Mast height above track is 7.5m.
   - U/S of portal above HTRL is 7.5m.
3. Single DV = S
4. Twin DV = T
5. Not to Scale.
6. Anchor = ●
7. Contact R.L. direction same as Catenary.
8. RL Factor : -ve to Left ; +ve to Right.
9. System is Regulated unless specified as Fixed Anchored "FA".
10. FA tensions & radial loads are maximum (Low temperature » High tension).



Viewed with Back to Sydney

Location : MH12+049 (Final) (Existing Beam)

© RIC - Electrical Design

Job No. : A/02/0123

Aspect	Equipment Number 1	2	3	4	5	6	7	8	9	10	11	12	Sum Forces
Wire System	B	E	B										
System Details (Catenary ; Contact)	270;2x137	165;193	270;2x137										
Weight Span (m)	30	31	30										
Wind Span (m)	0	0	0										
Radial Load Factor [L/R] @ 1kN Base (-/+)[8]	0.013	0.030	-0.013										
(Direction) ← →	= >	= >	< =										
Weight - Static (kN)	1.53	1.02	1.53										4.1
- Dynamic (kN)	2.60	2.09	2.60										7.3
Catenary - Height (m)	5.5	5.7	5.55										
- Regulated Tension (kN)	30.0	18.1	30.0										
- Max. F.A. Tension (kN)													
- Dynamic Wind Load (kN)	0.0	0.0	0.0										±0.0
- Radial Load (kN)	0.4	0.5	-0.4										0.5
Contact - Height (m)	4.9	5.05	4.9										
- Regulated Tension (kN)	25.0	18.0	25.0										
- Max. F.A. Tension (kN)													
- Dynamic Wind Load (kN)	0.0	0.0	0.0										±0.0
- Radial Load (kN)	0.3	0.5	-0.3										0.5
Anchor - Type (Fixed, Moving)													
- Wire Side (Sydney, Country)													
- Special Anchor ? (FSAM)													
- Total Weight Stack (kN)													
- Associated Track													
- Typ. Arrangement Drawing													

Comments :
OOR crossover and PRL OHW supported from existing beam.

	Drn	Ckd	Revision
Date			1.0

Figure 305 - Sample "OHW Loading Diagram" - inside the Railway Enclosure Structure at Chatswood

STRUCTURE FABRICATION

Because of the close proximity to both Newcastle and Port Kembla Steelworks (at least until recent times), the cost of steel used to be relatively cheap for NSW Railways, compared with many overseas places (and probably even compared with other states). This made thicker standard sections such as Universal Columns more accessible and cost effective when designing and fabricating the various OHW structures needed for Sydney's electrified network. And economies of scale can also come into play.

In areas where steel is relatively expensive (such as in certain parts of Europe), I think the tendency is to use lighter gauge steel and strengthen this with welded bracing sections, producing products such as *lattice* structures. It's a case of "swings and roundabouts" here. The structures might be lighter (which is good), but the labour component to perform the necessarily large number of discrete welds can be quite a burden and expensive. (These days robotic welding has likely changed this situation dramatically.)

However, the significant down side to the lattice structure approach is that corrosion can quickly establish itself if the initial paint or galvanized coating is not properly and thoroughly performed. The multitude of welded connections results in many nooks and crannies, and these can make it difficult to properly prepare the various surfaces and thus protect the steel in the first place. And anyway, these are areas where water can naturally collect and accelerate the corrosion process.

Even if proper galvanic protection is achieved, later on when corrosion finally sets in (as it inevitably does), it can become difficult to gain unobstructed access to remove any rust and effectively reprotect the surfaces and multitude of connections. $$$.

Contrast this situation with the use of open sections such as the simple Universal Column – it is relatively easy to observe any corrosion, and also to access most of the surfaces should any corrosion commence. If needed, this makes retreating the surface easier and more effective.

However, sometimes a project might demand the use of the more expensive lattice structures, often just in certain areas. This has happened in places like:

- Goulburn Street Viaduct leading into Central Station – a heritage requirement was in place to better match the existing structures they were replacing nearby or in-situ – *Figure 302*.
- Sydney Harbour Bridge – the renewed structures were to also be lattice type (per existing). For example, refer to the relevant photo in *Figure 314*.
- Dapto to Kiama – all new OHW structures through stations (a contractual requirement). Refer to *Figure 319* further on, for instance.

CONCRETE POLES ARE UNACCEPTABLE

For a long time now, *concrete poles* were (and probably still are) unacceptable for installing OHW on within Sydney's OHW system.

I understand this was due to major concerns over the significant risk of any accelerated dc corrosion to the important steel reinforcing located within the pole, and its consequent loss of strength integrity.

The increased risk is due to the immediate proximity of the poles to dc electrical current from the OHW conductors (through their support & registration insulation), and/or through the traction return rails (leaking back to the substation via any available conductive path).

Note that any corrosion taking place would more than likely be either difficult to detect (e.g. minor concrete spall from the rust expanding) or totally hidden from view, and may remain undetected until failure occurs. Thus the concern.

OHW Structure Drawings

Table 27 is a listing of OHW structure drawings obtained from Civil Design document TMC-331, "Design of OHW Structures & Signal Gantries".
Unfortunately, this will likely be quite out-of-date now.

Safety Barriers

Refer to Standard EP-08160002-SP, "Safety Barriers for OHW Structures".

3.3.0.6 Status (c. 2014)

Wood poles are to be used for emergency purposes only, unless the life cycle cost of using a wood pole in place of steel deems it more appropriate. They tend to be reserved for the occasional damaged OHW situations, in a short-term effort to get trains running again as soon as possible.

3.3.0.7 Reference

TMC-331, "Design of Overhead Wiring Structures & Signal Gantries"

Figure 306 - Some Masts need to be very tall (Central Flyovers)

Drawing No	OHWS Drawing
CV 0373001	PP2 Mast & PP3 Mast Steelwork & Footings
CV 0373002	HP2 Mast & HP3 Mast Steelwork
CV 0373003	HP2 Mast & HP3 Mast Footings
CV 0373004	200 SHS Portal Steelwork
CV 0373005	200 SHS Portal Footings
CV 0373006	250 SHS Portal Steelwork
CV 0373007	250 SHS Portal Footings
CV 0373008	300 SHS Portal Steelwork
CV 0373009	300 SHS Portal Footings
CV 0373010	250 SHS Cantilever Mast Steelwork
CV 0373011	250 SHS Cantilever Mast Footings
CV 0373012	300 SHS Light Cantilever Mast Steelwork
CV 0373013	300 SHS Light Cantilever Mast Footings
CV 0373014	300 SHS Cantilever Mast Steelwork
CV 0373015	300 SHS Cantilever Mast Footings
CV 0373016	300 Double Channel Portal Steelwork
CV 0373017	300 Double Channel Portal Footings
CV 0373026	Guy Footings
CV 0373027	Guy Pile & Guy Rock Footings
CV 0373028	DS Drop Vertical & DSW Drop Vertical Steelwork
CV 0373029	DT Drop Vertical & DTW Drop Vertical Steelwork
CV 0373030	Free Standing Anchor Masts Steelwork & Footings
CV 0373044	Repair for Exposed Mast Footings
CV 0373046	Cutting Bridge Support Replacement Type 1 & Type 2
E1- 437	380 Double Channel Portal – Steelwork
E1- 438	380 Double Channel Portal – Footings
E1- 448	300 Double Channel Signal or Feeder Structure – Steelwork
E1- 449	300 Double Channel Signal or Feeder Structure – Footings
E1- 450	Double Channel Feeder & Signal Structure – Walkway & Balustrade Steelwork
E1- 451	Double Channel Feeder & Signal Structure – Ladder & Cage Steelwork
E1- 452	Signal Cage Steelwork
E1- 453	Ladder Landing Footing
E1- 454	410 Double UB Portal – Steelwork
E1- 455	Access Prevention Grill Steelwork
E1- 456	460 Double UB Portal – Steelwork
CV 0047941	Cantilever Signal Structure – Steelwork
CV 0055980	250 SHS Double Cantilever Mast – Steelwork
CV 0142949	Footing in Retaining Wall
CV 0144833	Boxed Free Standing Anchor Mast – Mast & Footing Details
CV 0465528	Guy Bracket on Rock Face
CV 0364937	Double Channel Feeder & Signal Structure – Balustrade Gate at Signal Cage Steelwork

Table 27 - OHW Structure design drawings (from TMC-331)

3.3.1 Wood Poles

3.3.1.1 Description

Wood poles can be used to support OHW conductors, and sometimes they also incorporate HV aerial feeders (transmission lines) located higher up the pole.

Figure 307 - Cantilever installed on wood Pole (damaged)

3.3.1.2 Function

Wood poles provide the various functions of support structures. Their major benefit is that they can be installed quickly by Electrical staff, and can be particularly versatile in emergency situations where existing steel OHW structures have been damaged. Refer to *Figure 307*.

3.3.1.3 Typical Components

A wood pole is basically the same as a pole used for HV aerial lines (transmission lines), although they need not be as tall to hold the OHW above a track.

A pole includes:

- The wood pole itself (which has a slight taper over its length – it's wider at the base than at the top).
- A galvanised steel pole cap at the top (to help seal the pole in order to slow down any dry rot, insect infestation, etc.).
- Climbing pegs (installed above a certain height to prevent easy access).
- Pole ground treatment (to prevent termites, dry rot, etc.).

3.3.1.4 Configuration

A range of pole sizes and strengths is available to suit most OHW situations.

Wood poles were commonly used throughout the network, as they were relatively cheap, easy to install beside the track, and importantly they could be installed by Mains staff at very quick notice (once loading calculations were done to confirm the pole height & girth). Contrast this with steel structures which need to be designed and erected by Civil staff and is a slower process (but yielding a more permanent solution).

They seemed to be used in large numbers in sidings and yards, but rarely in main lines or other system-critical areas.

These days wood poles are normally reserved for emergencies (such as when a steel mast or portal is accidentally knocked down) as they can be installed by Electrical staff very quickly.

Figure 308 - Wood Poles on Richmond Line

In these emergency situations, if more than one run of OHW is involved, two poles can be installed in conjunction with a *polygon* arrangement, to quickly support and align the OHW conductors. (One pole is installed on each side of the track corridor – refer to *Section 3.2.3*, *Polygon Arrangements*.) But this would depend on the tension modes of the various connected OHW bays (fixed-anchored OHW is less complicated).

Certain OHW *cantilever* arrangements have been designed for installation onto a wood pole, thus providing a means of supporting both regulated and fixed-anchored OHW. The "Mast" computer program was modified to include Mark-1 cantilevers installed on wood poles – the program was named "MastWood" – see *Section 3.2.1.5*, *"Mark-1" Cantilevers.*

Table 28 shows the approximate population of wood poles used for supporting OHW throughout the electrified network, as it was in 2012. I suspect the numbers are now much diminished, as a concerted effort was being made to modernise all OHW, including on track routes with predominately wood poles (replacing with steel masts).

The Carlingford line (in the West district) still had a large population of wood poles servicing the OHW even to the year 2019, but they've since been totally removed for a dedicated light rail service with its particular OHW being constructed in 2020.

District	Approx. No. of Wood Poles Remaining *	Comment
North	0	
Central	67	
West	402	
Illawarra	8	
Total	**477**	

* As at beginning of 2012 – obtained from RailCorp Asset Explorer.

Table 28 - Wood Pole Population By District

3.3.1.5 Design Notes

WOOD POLE

Note that "wood" is the natural fibrous material of a tree, whereas "timber" is machined products made from wood, such as beams or planks.

I guess the fact that these poles are not machine sliced into smaller sections, but are simply processed (bark removed, trimmed for a specific top and bottom diameter, etc.), they are termed *wood* poles (and not *timber* poles).

All poles are made from various species of *hardwood*. The pole details, including species, strength, etc. are stamped typically on a metal disc that's recessed into the pole for future reference.

POLE CAP

The steel pole cap is a vital part of the pole, as it helps keep the water from wicking down the centre of the pole. This in turn helps preserve the pole's centre, against various types of rot and deterioration, which can lead to an internal "pipe" (see below).

It also helps keep to out various insects such as the termites, which can play havoc to the strength of the pole over time.

A POLE "PIPE"

The other aspect that affects the pole's serviceability is whether it has an internal "pipe". This is a somewhat cylindrical cavity formed over time in the centre of the pole where the timber's resistance to decay is weakest.

Measurements can be made to determine the annular *thickness* of sound timber remaining, by drilling into the timber at various levels (and plugging after the measurement is made). Calculations can then be performed to determine the likely amount of *residual strength* in the pole. This approach depends on calculating the worst-case loading (bending moment) at the base of the pole, and knowing the wood species and other factors, so a determination can be made whether the pole remains fit for service, or planned for renewal, or immediately "condemned" and renewed.

TERMITES

Termites are nasty insects that can infest a pole and eat away at the timber fibres. Over time, this can destroy the strength of a wood pole, and can ultimately cause it to break and fall, often with little advance warning.

Termite "galleries" are one of the first signs of termite activity in a wood pole, as seen in *Figure 309*.

These galleries are routes built by the termites from mud, saliva, etc. to form a barrier from the external world, including sunlight. This allows them to traverse the pole any time and perform their munching damage. Yum.

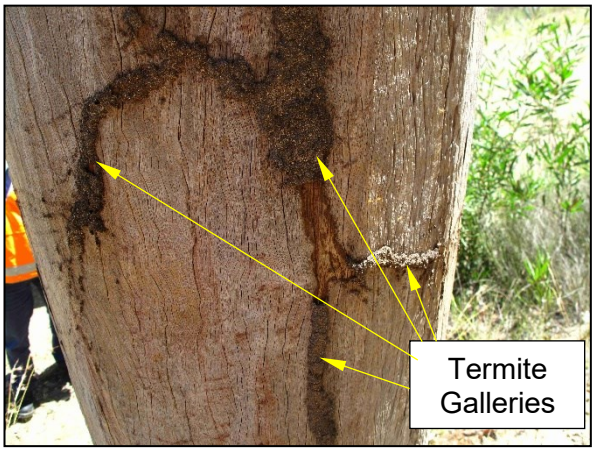


Figure 309 - Termite galleries on Pole

DAMAGE AT POLE BASE

The *base* of a pole is another area that is often subject to damage from all sorts of things, including termites, dry rot, fungal attack, etc.

The pole base is extremely important because this is where the *maximum bending moment* is applied to a pole, and so that's where its greatest strength needs to be.

In the old days they used to coat the base of the pole, before installing, with *creosote* from bottom of pole to just above ground level. This black-coloured treatment would be periodically repeated (as far as is practical below ground). Apparently, creosote can have nasty effects on people if protective gear is not worn, so these days other chemicals and processes are available to help preserve the pole base.

For example, about 20 years ago, a commercial item "PresChem" was applied as a pill-laden bandage that was wrapped around the exposed base of the pole. The chemicals within the pills gradually leached in a focussed way into the pole base to do their magic, over a long period of time. Of course, they would eventually need replacing.

Note that "Bioguard" bands were and are apparently used also. And there are likely updated chemicals and/or approaches to pole preservation these days – I'm not sure.

LIGHTNING STRIKES

Pole damage can also come from direct lightning strikes, which can totally shatter the pole, or split it vertically.

Either the pole is totally destroyed or it can be greatly weakened as a result.

EFFECTS OF DETERIORATED POLE

Figure 310 shows what damage can happen if a wood pole supporting OHW is allowed to deteriorate until failure. (It's enough to give a train a decent headache!)

I think the cause here was termite activity within the pole, as shown in the left-side photo. Or was it a lightning strike?

Figure 310 - Wood Pole failure causing damage to train (Riverstone 2009)

3.3.1.6 Status (c. 2014)

Wood poles are only to be used in emergency and temporary situations, or where economically justified (life cycle cost) in non-critical areas.

3.3.1.7 Reference

See drawings D/81571 and D/81572 for typical wood pole details (species, strength, size, etc.).

3.3.2 Steel Masts

3.3.2.1 Description

Steel masts appear as single, tall, vertical steel sections installed in the ground (with OHW support and registration equipment attached). See *Figure 311*.

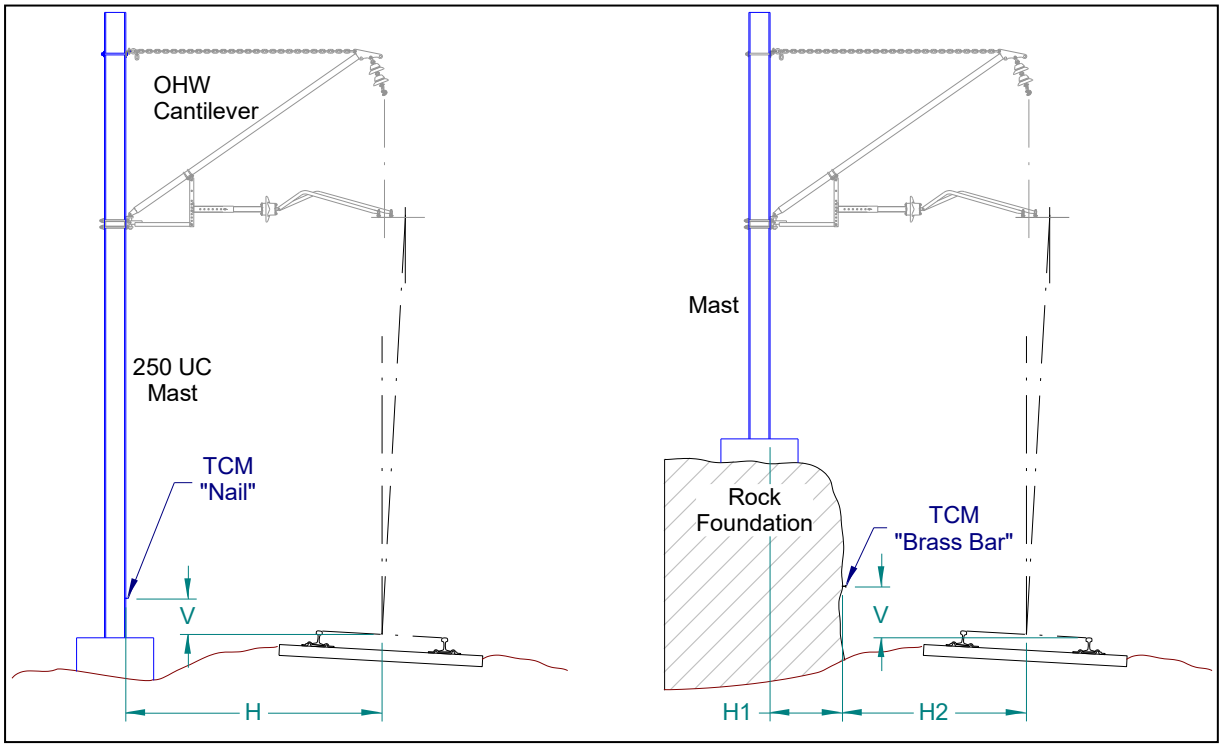


Figure 311 - Masts installed in ground (left) or on rock (right)

3.3.2.2 Function

Steel masts support OHW conductors and their support and registration equipment. They also hold any radial and wind loads imposed on these conductors.

The structures are reasonably stiff, to prevent excessive deflection with wind, which is required to help assure pantograph security.

3.3.2.3 Typical Components

These include:

- The length of steel mast (which may include a welded base plate with holes provided for taking the hold down bolts).
- Concrete foundation (which may be steel reinforced, depending on type of installation).
- Hold down bolts and associated nuts that connect the mast to a concrete foundation (depending on type of installation).

3.3.2.4 Configuration

Masts are currently made from solid steel sections, such as "Universal Columns" (UCs) or sometimes "Square Hollow Sections" (SHS).

A "PP" is a "planted post" type mast. A hole is bored in the ground into which a steel mast is inserted and surrounded with concrete, thus providing the cheapest mast installation.

The alternative is an "HP" mast (or "HPM") with welded base, which is placed over several hold down bolts that are cast in the concrete foundation. A nut and lock nut is installed on each bolt and suitably tensioned.

Older types of masts were often pre-fabricated, constructed from mild steel plates and angles riveted or welded together to form a light but strong mast. Typical examples are:

- F & T masts
- S masts
- LPO (Light pull-off) masts
- HPO (Heavy pull-off) masts
- Rail masts (constructed from track rails, and often back anchored so that polygons could be installed)

Refer to drawing F/23240 sheets 1 to 7 for details on the above masts.

Masts are generally no longer fabricated from small parts due to the intensive labour involved in their construction, when compared to the efficient UC or SHS extruded sections available these days. Also, any connection point can be cause for potential corrosion over time.

For the past 40 or 50 years masts have mostly been constructed from large rolled UC sections, e.g. 250 UC is a 250mm × 250mm Universal Column section. (Note that the external dimensions can be a few mm different from this size.)

Current typical mast sizes are shown in *Table 29*.

Mast Reference	Cross-sectional Size & Density	Comments
PP	250 × 250mm UBP 63(kg/m)	Standard mast
PP2	250mm × 250mm UC 73(kg/m)	Heavy duty mast for high radial, wind and weight loads
PP3	310mm × 310mm UC 97(kg/m)	Heavy duty mast, mostly intended for supporting highly tensioned OHW systems with twin weight tension regulators & as anchor masts

Table 29 - Masts for new construction

3.3.2.5 Design Notes

The uniform section of a UC mast allows its deflection to be calculated and taken into account by the CCalc computer program (which generates construction details for OHW cantilevers).

The nominal "Rake" on a mast is 17mm (in 2,000mm vertical), in the direction leaning away from the supported track. Refer to Section *3.3.0.5*, *Mast Rake & Deflection*.

Some masts can be made very tall if needed – see further back in *Figure 306*.

3.3.2.6 Status (c. 2014)

Prefabricated masts (constructed from many welded sections) are rarely used – single rolled steel sections are generally employed instead (see *Table 27*).

3.3.2.7 Reference

Refer to drawing F/23240 sheets 1 to 7 for details on older type pre-fabricated masts.

Refer to Civil Design section for current relevant drawings of standard masts.

3.3.3 Steel Portals & Drop Verticals

3.3.3.1 Description

Steel portals (or "gantries" as they are sometimes called) appear as structures with 2 (or more) "legs" and with a top horizontal steel portal "bridge" connecting them (at about 7.5m height above track).

Portals often include one or more *drop verticals* suspended from the bridge (drop verticals are considered to be part of the portal). A *Single DV* appears as single vertical length of steel, sometimes with a diagonal brace, suspended down to about contact wire height (to register this wire). A *Twin DV* comprises 2 single drop verticals spaced about 1m longitudinally apart and connected at the top from a common bridge connection.

See *Figure 294* further back for a view of the main components of a portal structure.

3.3.3.2 Function

Steel portals support the weight, radial and wind loads imposed by the various OHW conductors. The structure is rigid to prevent its excessive deflection with wind.

The advantage of steel portals over other structures is that they can span many tracks and are thus able to provide convenient independent OHW support & registration from drop verticals located between tracks.

3.3.3.3 Typical Components

These include:

- Steel legs, bridge and associated stiffening knee-braces. This includes all associated fasteners (nuts & bolts) for connecting portal legs to portal bridge & for connecting diagonal knee-braces between legs and bridge.
- One or more drop verticals (if required).
- Concrete foundations, including several cast-in hold down bolts (these need to be formed well before the structure is erected).
- Hold-down nuts & lock nuts, to clamp legs to foundations.

3.3.3.4 Configuration

Portals come in different sizes, depending on the number of tracks the portal bridge spans, e.g. 1-track, 2-track, 4-track, 6-track, 8-track, etc.

They also come in different shapes, which can sometimes be dictated by project aesthetic requirements. See *Figure 312* for a recent portal installed at Milsons Point Viaduct and *Figure 313* for unusual "Whalebone" structures at Chatswood. Refer also to *Figure 314* for some other examples of different styles of portal structures in Sydney's OHW system.

Portals normally have 2 "portal legs" which are typically masts bolted to a concrete foundation, and which support the portal "bridge" (or "boom" as it is sometimes referred to). Special "knee-braces" are installed near each junction between leg and bridge to offer additional stiffness to the overall structure, and to help support the portal bridge.

The bridge itself is often designed to include "camber", which is an upward curve towards the middle of this beam. It's designed to take into account the bridge's deflection under weight load (gravity), so that it becomes flat or near-flat when finally loaded. (Unfortunately, if the bridge were to belly down in the middle, this tends to suggest it's overloaded even if it's not, and this may prompt continual queries as to its suitability throughout its life.)

Portal bridges made from square hollow section (SHS), as shown in *Figure 312*, do not include camber, I think partly because it would be difficult to introduce it without weakening the beam in the process. Also, the SHS section is relatively light, strong and quite stiff, which suits this situation.

Some portal legs have pin joints at the concrete foundation. This type minimises the bending moment at the foundation, but requires the upper part of the portal to be stiffer to keep its shape and prevent excessive deflection, especially under high wind speeds.

Where tracks pass through rock cuttings, the rock walls can take the place of one or both portal legs. In these cases, the portal bridge is secured to the rock by some connecting steelwork and various types of anchor bolts. Refer to *Figure 324* a bit further on.

Figure 312 - Recently installed Portal Structures on Milsons Pt Viaduct

Figure 313 - "Whalebone" Structures at Chatswood supporting OHW

Combined OHW / Signal Structure at Central

OHW Portal on Sydney Harbour Bridge

Double Channel Portal on Central Flyovers

Architectural Portals on ESR Viaduct

OHW Feeder / Support Structure at Central

Compound OHW Portal at Emu Plains

Figure 314 - Various OHW Portal Structure styles & applications

KNEE-BRACES

Knee-braces are employed near the right-angle junction of a portal vertical leg with its horizontal bridge, to stiffen the whole portal structure and help support the bridge. Refer to

Figure 294 and *Figure 295* further back. Note that they are not always needed, especially if the portal legs are already stiff enough by themselves (e.g. 250 SHS leg) and the bridge is relatively short (e.g. for single track), but this is a decision for the structure designer.

Figure 315 has 2 adjacent Cantilever & Nose structures supporting 4 cantilevers (needed for the overlaps installed above each tightly-curved track). The legs of each structure use knee-braces to help provide a strong and stable bridge. (In this instance the catenary heights are lowered to prepare for passing under a nearby bridge or tunnel.)

Figure 315 - Cantilever & Nose Structures (Waverton)

Each knee-brace typically consists of 2 lengths of steel angle – one located on each side of the portal leg – with associated parts that connect to vertical leg and to horizontal bridge. The connection to portal leg is typically 2m down from the bridge connection, and connection to bridge is 2m in from the leg, making the lengths of steel angle about 2.8m long and inclined at the tell-tale 45° to horizon.

They also include one steel plate (batten) located midway along the length of knee-brace, that is welded to the 2 steel angles to provide the long steel angles with some additional rigidity. For larger double-channel portals there are 2 such battens roughly equally spaced along the length of steel angles.

In some instances, OHW cantilevers mounted within the inclined steel angles of these knee-braces will have restricted swinging movement unless a "wide knee-brace" (WKB) is called up. However, I think this configuration is now virtually standard since the 1990s (and is certainly what's shown in the above figure).

In a regulated OHW system, this WKB then provides additional longitudinal space which gives unimpeded freedom for the cantilever tie-rod & chain and cantilever pipe to swing horizontally in response to temperature-induced catenary and contact wire movement. This

movement can be up to about ±500mm from some "normal" position perpendicular to track.

Note:

For *regulated* OHW:

- The actual amount of cantilever movement with temperature depends on how much OHW conductor movement is anticipated at that location, i.e. how far the particular structure is from the fixed anchor or fixed mid-point anchor of that particular wire run.
- The actual clearance from cantilever to knee-brace also depends on how far out the cantilever needs to reach the conductors beyond the knee-brace, e.g. if the tie-rod portion is twice as long as the knee-brace, then only half the conductor-generated movement appears on the tie-rod at the knee-brace position. The 45° incline of the knee-brace can also help enormously in this regard – the lower down the tie-rod & chain are relative to the knee-brace, the less the restriction between the 2 steel angles. This situation can be seen in *Figure 316*.

One of the challenges that the CCalc computer program faces at times (and resolves) is to calculate a cantilever that clears the mid-batten(s) of the knee-brace. This includes the horizontal tie-rod & chain and sometimes the diagonal pipe (jib) that both need to pass in between the 2 steel angles of the knee-brace, and also clear the 1 or 2 installed mid-battens linking these knee-brace angles together And the mast attachment bracket at the lower end of the pipe need to also clear the bottom knee-brace connection to the portal leg. *Figure 316* is included to demonstrate this situation. CCalc assesses this situation and chooses a standard pipe length that's compatible in each case.

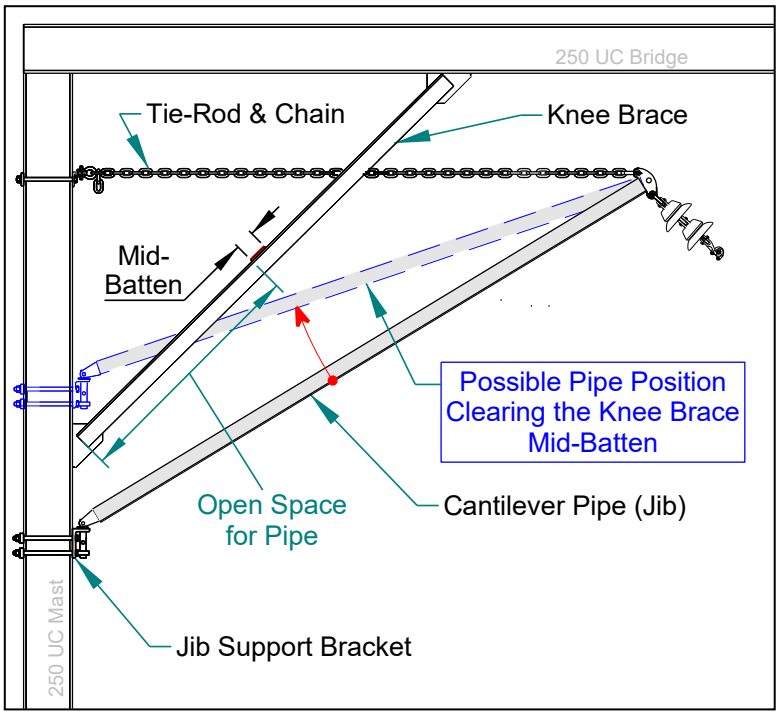


Figure 316 - Knee-Brace mid-batten impediment

Of course, CCalc can only perform this important clearance function if the geometry of the various standard knee-braces and their mid-battens, remains the same as they were originally designed (in the mid-1980s). If these dimensions have changed, then there may be the need for much time-consuming adjustments in the field when cantilever parts eventually clash during installation, which is bad because time on the track (without trains running) is precious, and because this can adversely (& unfairly) affect CCalc's reputation in terms of its perceived accuracy and usefulness.

Note that there should be no substantial loading placed on the knee-brace itself, just in case it causes buckling (with consequent reduced structural integrity).

DROP VERTICALS

A drop vertical (DV) is a wonderful piece of equipment. It can offer many significant advantages when OHW needs to be supported and/or registered, and it can also offer solutions in awkward situations. (See *Figure 328* at the end of this section for instance).

Situations

Portals often include one or several DVs installed from the portal bridge. However, DVs can also be mounted from the underside of various structures, including:
tunnel ceilings, flat ceilings at underground stations, under overline bridges, and on many other common structures and situations.

Drop verticals offer convenient installation of various OHW support & registration equipment (especially cantilevers), and they are most often located in between tracks. When installed between tracks, DVs can provide the means of achieving *independent registration*, which is really important these days to help improve the reliability of train operations.

The nice thing with DVs is that they can be squeezed in between closely spaced tracks (down to about 3.2m track centres or so, depending on the track superelevations of both adjacent tracks). Also, their length comes from directly above, down into the vacant clear space provided by the diagonal sloping part at the top of each train. *Figure 317* gives an idea of this space (for more details refer to "PanGauge" output further on in *Figure 695*). Their actual lengths are sized to be long enough to mount the appropriate pull-off arrangement near the bottom (with room for adjustments), but should not be so long as to collide with the upper diagonal part of a train. (Drop vertical should clear both the *pantograph gauge* and the *structure gauge*.)

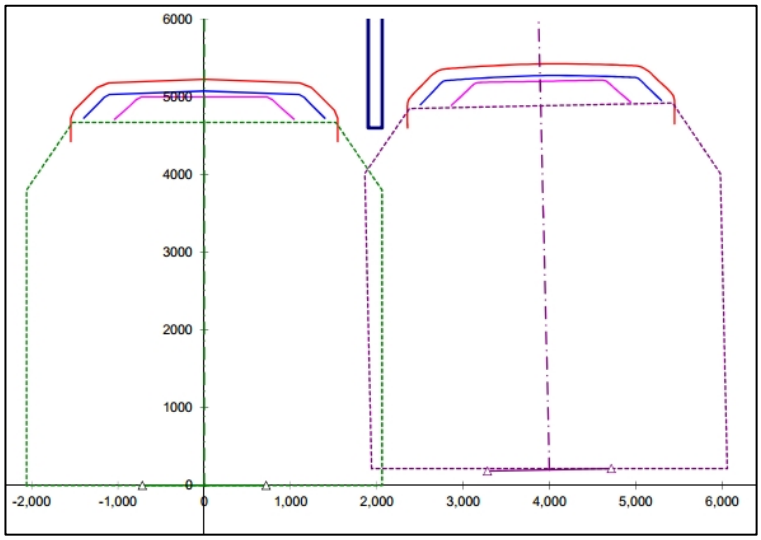


Figure 317 - "PanGauge" asssessment of DV installed between tracks

There can be several DVs installed from the same portal bridge and with a mix of single and twin DVs (provided the portal has been designed to cope with such loads). This can help to provide an orderly setout of structures along the rail corridor (without the need for many other structures in a somewhat random fashion and the resulting "picket fence" effect).

Civil Design

The OHW designer usually supplies a "Drop Vertical Length & Position Table" spreadsheet output to Civil Design. *Figure 320* is an example of portion of the table for a recent project.

This table helps relate the DV position to the design vertical centre of track, which is a more obvious reference when installing the drop vertical – see the 2nd last column headed "**H**" (for Horizontal offset) which has the required value to the design vertical centreline of track.

Note that the last column of this table, headed "**V**" (for Vertical offset), gives the approximate minimum height of the drop vertical needed for electrical purposes (in order to clamp the pull-off bracket). This information is used by Civil Design to establish the required standard drop vertical length to suit that particular situation.

Along with a relevant *OHW loading diagram* for the particular location, they then have sufficient information to design the OHW structure, including the specification and location of all its drop verticals.

Any portal structure that has twin drop verticals installed on it needs to take into account out-of-balance loads which tend to rotate the portal bridge. Often the bridges of these portals are

made from double channels or square hollow sections, which better cope with any such twisting action. Single universal column bridges are usually unsuitable in this situation.

Position Relative to Track

The drop vertical is positioned at a set horizontal distance relative to the superelevated centreline of design track position (at contact height level), as shown back in *Figure 209*. For more details see *Section 3.2.1.5, Location of Drop Verticals to Track*.

Clearance

The bottom of the DV is typically designed to come down to a level that's about 200mm to 300mm below the contact wire height. This provides some vertical space for the pull-off arrangement to be installed, and adjusted vertically in case something changes in the future. But it depends on how low the contact wire height is.

The closest face of a drop vertical should be at least 1.55m laterally clear of the superelevated centreline of any adjacent track (at contact height), so as to gain suitable train passing clearance to avoid striking the DV. This is provided the bottom of the DV doesn't go too much below contact height. The 11th column in the table of *Figure 320* helps in this regard.

Ultimately, clearance to the "structure gauge" is to be achieved. This is crucial if the bottom of the DV is very low relative to the trains (i.e. low contact height situations). As mentioned above, the diagonal shape near the top of a train can help gain suitable passing clearances, but the lower the bottom of the DV is in this area, the greater its lateral clearance needs to be.

Figure 317 may help give a better appreciation of this situation.

Drop Vertical Types

The recent drop verticals that were generally available for use are listed in *Table 30*. (Much older drop vertical types are not given.)

Dropper Type	Description	Old Civil Drawing No.
DS	Single 200 U.C. Drop Vertical (no brace)	E2-209
DSW	Single 250 U.C. Drop Vertical (no brace)	E2-209
DA	150 U.C. Drop Vertical, with inclined brace to portal bridge.	E1-165
DM	150 U.C. Drop Vertical, located within portal knee-brace, with horizontal brace back to portal leg.	E1-169
DR	102x76mm Drop Vertical, with diagonal brace to portal bridge and horizontal strengthener. (Old design)	E3-118
DT	Twin Drop Vertical, 250U.C., spaced 1 metre apart. For use with double channel portals.	E2-210
DTA	Twin Drop Vertical, 200U.C., spaced 1 metre apart.	E2-229
DTW	Twin Drop Vertical, 250U.C., spaced 1 metre apart. For use with double channel walkways.	E2-210

Table 30 - Drop Vertical types

Drop verticals come in different configurations, including (but not limited to):

- "*DR*" type braced drop verticals. This is an older style of braced drop vertical, and a number of standard lengths were available. The specific configuration is associated with a sub-number, e.g. "DR-6" was 2,970mm long and "DR-9" was 2,440mm long. Refer to *Figure 319*, and also to *Figure 323* with a DR type drop vertical located between tracks.

The one significant benefit of this DV is that it is only 76mm deep in a longitudinal sense (the vertical member is a 203 × 76mm channel). This makes it sometimes desirable to use in situations with narrow track centres, where the standard 150 UC (162mm deep) drop vertical is too thick. (The DR drop vertical may allow the structure to be placed a few metres further along in the bay, which may provide a better outcome for wiring a crossover for instance.)

- "*DS*" type "Single" Universal Column drop verticals (with no brace up to the portal bridge). The typical steel size these days is 150UC, however 200UC & even 250UC sizes have been used in the past. *Figure 315* shows this type of DV. See also *Figure 318*.
- "*DT*" type "Twin" drop verticals, are essentially twin versions of the DS drop vertical (outrigging each drop vertical about 500mm on either side of the centre of portal bridge). The drop verticals are typically 150UC and are spaced 1m longitudinally apart. See *right* view of *Figure 296* and also *Figure 455*.
  Note: Need to be careful that the portal bridge is designed for the out-of-balance loads from 2 (or even up to 4) OHW cantilevers installed on the twin drop verticals, and not cause the bridge to twist. (This includes the staging of wires transferred to the DVs.) Otherwise the position of the attached OHW conductors, and the strength of the structure itself, may be compromised.

Figure 318 - Lattice-type OHW Structure with DS Drop Vertical (Enfield, c. 2012)

As mentioned above, sizing the *length* of each drop vertical is important. They must be:

- Long enough to hold the bottom pull-off fittings (without the need for any extension plate to lower further).
- Not so long that it infringes the Pantograph Gauge "Electrical Clearance" envelope, nor the Structure Gauge.

Figure 319 - "DR" Drop Verticals on Lattice Bridge Structure (Dunmore c. 2011)

Drop Vertical Length & Position Table

Project : PRL - CHATSWOOD INTERFACE - Final Stage

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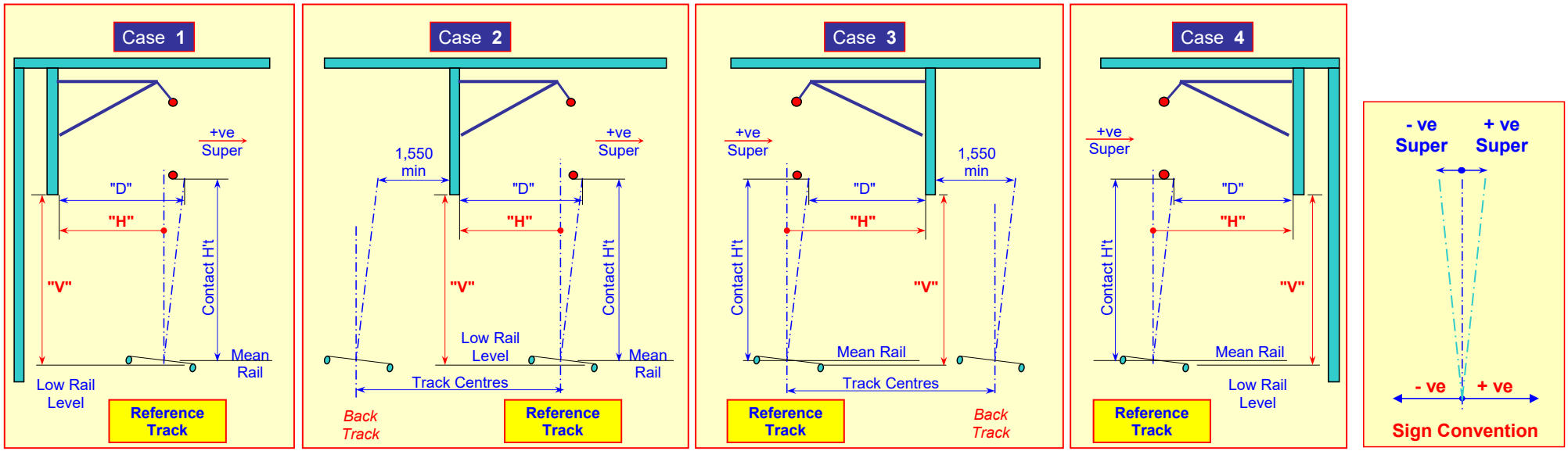


Notes :
1. Viewed with Back to Sydney.

					Sign	Cases 2 & 3 Only		162 ?	Vertical Distance		(1,550 to back track)	DV Half Way	Always +ve		Clearance Check	Output for Civil Design	
Location No.	**Reference Track**	**Case No.**	**Contact Height (mm)**	**Track Super @ Ref. (mm)**	**Track Centres (mm)**	**Track Super @ Back (mm)**	**Width of DV (mm)**	**Contact to DV Bottom (mm)**	**Super to Super Distance (mm)**	**Maximum Distance "D" (mm)**	**Distance to DV in Mid Position (mm)**	**Distance from DV to Super C/L Ref. Track (mm)**	**Distance to Super C/L of Back Track (mm)**	**Distance to Back less 1,550 (mm)**	**Distance to Vertical C/L Ref. Track (mm)**	**Bottom of DV to Low Rail Level (mm)**
Final																
MH12+016	Dn NSL	1	4,800	0				300	N/A			1,800			-1,800	4,500
MH12+016	Up PRL	2	4,800	0	4,000	0	162	300	4,000	2,288	1,919	1,920	1,918	368	-1,920	4,500
MH12+016	Up NSL	4	4,800	0			162	300	N/A			1,800			1,800	4,500
MH12+019	Dn PRL	3	4,800	0	4,000	0	162	300	4,000	2,288	1,919	1,920	1,918	368	1,920	4,500
MH12+046	Dn NSL	1	4,800	0			162	300	N/A			1,800			-1,800	4,500
MH12+046	Dn PRL	2	4,800	0	4,000	0	162	300	4,000	2,288	1,919	1,920	1,918	368	-1,920	4,500
MH12+046	Up NSL	4	4,800	0			162	300	N/A			1,800			1,800	4,500
MH12+049	Dn NSL	2	4,800	0	4,000	0	162	300	4,000	2,288	1,919	2,200	1,638	88	-2,200	4,500
MH12+049	Up PRL	2	4,800	0	4,000	0	162	300	4,000	2,288	1,919	1,920	1,918	368	-1,920	4,500
MH12+049	Up NSL	3	4,800	0	4,000	0	162	300	4,000	2,288	1,919	2,200	1,638	88	2,200	4,500
MH12+077	Dn NSL	3	4,800	0	4,000	0	162	300	4,000	2,288	1,919	1,800	2,038	488	1,800	4,500
MH12+077	Dn PRL	3	4,800	0	4,000	0	162	300	4,000	2,288	1,919	1,920	1,918	368	1,920	4,500
MH12+077	Up NSL	2	4,800	0	4,000	0	162	300	4,000	2,288	1,919	1,800	2,038	488	-1,800	4,500
MH12+079	Dn PRL	2	4,800	0	4,000	0	162	300	4,000	2,288	1,919	1,920	1,918	368	-1,920	4,500
MH12+079	Up PRL	2	4,800	0	4,000	0	162	300	4,000	2,288	1,919	1,920	1,918	368	-1,920	4,500

Figure 320 - Sample "Drop Vertical Length & Position Table" for Chatswood

CANTILEVER & NOSE STRUCTURE

A special arrangement, known as the "cantilever & nose", is like a portal cut in half (mid track) with a drop vertical installed at the cut end. (The "cantilever" is the portal bridge and single leg, and the "nose" is the drop vertical.) *Figure 321* has a location with 2 such arrangements installed about 2m or 3m longitudinally apart at an overlap (at Chatswood). See also *Figure 315* as other examples.

Figure 321 - Twin Cantilever & Nose arrangements

This arrangement is particularly useful in certain circumstances where it is essential to have a drop vertical located on the remote side of a track, but where it would be difficult to install the second (remote) leg of a normal portal structure. It might be that there's a roadway, or a steep embankment, or some clearance requirement due to safety considerations, that prevents the other leg from being installed. It may also incur considerable cost in its establishment.

A good example of the need occurs at some station platforms where a significant concave track curvature requires a drop vertical (with installed OHW cantilever) to be lined up near the platform edge. See *Figure 322* for instance. The leg can be placed on the remote side of track, so there's no need for a structure located on the platform itself (which is a good outcome for several reasons). Note that the structure in this figure also anchors one set of OHW.

Figure 322 - Cantilever & Nose at Epping Station

A box section steelwork (typically SHS) used in this arrangement is required to reduce any twisting due to the OHW loads and regulated wire movement with temperature. Unfortunately, the box section and its strengthened foundation can make it relatively expensive, so it needs to thus be used with discretion.

Figure 323 shows an older cantilever & nose situation in the Blue Mountains, unusually including 2 drop verticals. In this case there was obviously no place to install the right-hand leg for a standard portal structure (probably because the land there drops away quickly and/or to allow space for some important vehicular access roadway there).

These structures necessarily have the single leg highly loaded. So, utmost care needs to be taken to ensure that it's installed in a firm foundation and both the leg and its connection to the portal bridge are sufficiently strong enough to cope with the various applied loads. It also

needs to be stiff enough for serviceability under windy conditions (to ensure pantograph security).

Also shown in *Figure 323* is a "DR" type drop vertical located in between the 2 tracks. It has the characteristic diagonal bracing on the remote side.

Figure 323 - Older Cantilever & Nose arrangement in Compound OHW system

PORTAL SUPPORTED FROM ABOVE

Figure 280 further back, shows a series of portal bridges located underneath the Chatswood RES (Railway Enclosed Structure). Each bridge was supported at or near both ends by special steel "stirrups", which in turn were connected to precast ferrules located within the concrete ceiling above. No portal legs (but lots of planning) needed.

PORTALS INSTALLED ON ROCK

Some structures simply consist of a portal bridge spanning the tracks and are connected at both ends to a rock formation.

The rock cutting for rail corridor shown in *Figure 324* (Blue Mountains) makes it impossible to install a standard portal. So special brackets are installed on the rock to support a portal bridge. (The left end has a short leg, so a knee-brace was included here.)

Figure 324 - Portal Bridge installed in rock cutting

OLDER STRUCTURES

There's probably a huge range of styles of OHW structures scattered throughout the electrified network, and of various vintages. Fortunately, many of the older structures have been replaced through a concerted effort of renewal of main line OHW over the past 40 years or so. However, the various yards and sidings may not have been so fortunate in this regard, and they may still have a range of old structures of different styles.

Below are a few of the more common older types of fabricated portal structures.

Warren Brace (Truss) Structure

This is a relatively lightweight lattice type structure, which saw extensive use in the early electrification works.

Figure 325 shows one such structure.

Apparently a "Warren Truss" is a steel frame formed with a series of triangles, which makes it a light but strong structure.

Some recent projects have called for the use of this type of bracing for certain OHW structures, probably for aesthetic reasons as they appear to be not as solid or obtrusive.

Figure 325 - Warren Brace type Structure

"AS" Anchor Structure

This is a strong structure, designed to withstand the enormous anchored tension loads of a fixed-anchored OHW system onto its bridge, without the need for guys. One such structure is depicted in *Figure 326*, on the northern approach to the Sydney Harbour Bridge.

Figure 326 - AS Anchor Structure (on northern approach to Sydney Harbour Bridge)

This picture was taken from within an overlap bay itself, and you can see the terminated out-of-running catenary and contact wires (with insulators) for both tracks, anchoring directly above the relevant track on the portal bridge. (There are 4 OHW runs passing within this overlap bay area.)

This structure also supports and registers the in-running wires.

The structure relies on diagonal bracing to help provide the required strength, in both the legs and in the portal bridge. The legs form an "A" frame in a side view, to help cope with the anchor loads down to ground. (Note that the usual and preferred way of anchoring the conductor loads is to install an anchor mast with accompanying anchor guy inclined at about 45°, from conductor height down to ground.)

In particular, the foundations for both legs need to be securely anchored to the ground or other structure (the steelwork of the SHB approach in the above figure). This is primarily because of the huge bending moments and other mechanical forces caused by the anchored loads at their respective heights.

The preference over the past few decades is to avoid these structures in future works. But sometimes the (re)use of this type of structure is dictated by heritage concerns.

Refer to *Section 3.4.1.4*, *"AS" Anchor Structures* for further information.

3.3.3.5 Design Notes

Portal Bridge Twist

OHW cantilevers installed on Twin DVs can sometimes cause excessive rotational deflection of the portal bridge and consequent misalignment of the OHW conductors.

So, extreme care needs to be exercised when designing the portal bridge to take this twisting moment into account. Normally this would require the bridge to made from SHS steel (with its exceptional ability to resist rotation), or double channel (DC) structures.

Universal columns are absolutely not suitable here as they do not tolerate such twisting loads and can unfortunately rotate quite a lot as a consequence.

Ultimately any skewed drop verticals resulting from bridge twist will likely alter the design stagger for the contact wires at that location.

Although this stagger error may be corrected locally, the staggers can unfortunately change further as the contact wires move longitudinally with temperature in a regulated OHW system. This movement can cause the direction of loading on the DVs to change, resulting in different DV skew angles (i.e. under hot and cold temperatures). The end result may be that staggers change in a dynamic sense (during the day), and this may affect pantograph security, either at the structure itself or at some point within the previous or next bay (i.e. this pantograph security situation is unlikely to be checked out during the design!).

Access Prevention

Access prevention grills may be required in certain circumstances, for obvious reasons. See *Figure 327* for instance.

For more, refer to *Section 3.8.0.5*, *Anti-Climbing Mechanisms*.

Figure 327 - Access Prevention Grill on Portal Bridge (Waverton)

Fixed-Anchored to Regulated OHW Conversion

The electrified network has undergone an enormous change over the past few decades, where older fixed-anchored OHW was upgraded or renewed to regulated OHW, and bringing with it all the many benefits of that "ideal" mode of tensioning.

One such advantage is the ability to use a much lower catenary support height. It could typically reduce from 7.06m (23'-2") and often higher in the old days (due to deep catenary parabolas in 73m bays or longer), down to 6.5m for the new regulated OHW (with 67m bays).

Importantly, this means that the portal bridge heights could be lowered accordingly.

But great care was needed where older portal structures were replaced with new portals with lower bridges. The new structures were typically stood 2m or 3m away from the old structure, but with the old wiring still attached to the old structure. This meant that the old catenary could sometimes touch the bridge of the new structure (due to insufficient sag from its support point in order to gain suitable clearances to the new portal bridge). See *Figure 719* much further on for an example of the type of situation.

So, at times it was necessary to temporarily install a post type insulator on the underside of the new portal bridge, in order to hold and guide the old catenary past the new structure.

However, in doing this, it alters – shortens – the Virtual Span figure of the catenary wire, and this can have a detrimental effect on the temperature / tension characteristic. This situation needs to be checked out for the affected wire run.

3.3.3.6 Status (c. 2014)

Cantilever & nose arrangements are used where economically justified.

Braced drop verticals (such as DR-6) are generally no longer used. However, they can be usefully employed in situations where narrow track centres demand a thinner DV for some better outcome, or where a project requires them (e.g. due to aesthetics) in certain circumstances.

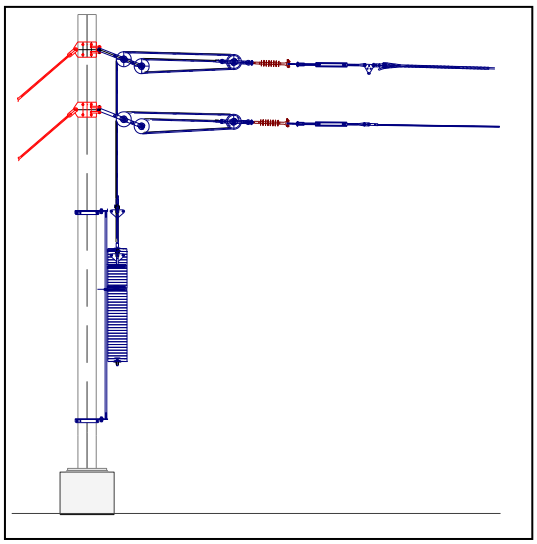
Where drop verticals are required, 150UC is generally the preferred size.

3.3.3.7 Reference

Refer to Civil Design section for drawings of the various portal and drop vertical arrangements.

Figure 328 - Drop Verticals installed from rock cutting (Dapto to Kiama)

3.4 ANCHORS



3.4.0 General

3.4.0.1 Description

Anchor arrangements appear at each end of a tension length of OHW conductors.

A "fixed mid-point anchor" is unusual in that it can appear roughly midway along a run of OHW conductors in a regulated OHW System (and creating 2 "tension lengths").

3.4.0.2 Function

Anchor arrangements in general do the following:

- They provide a means of terminating the catenary and contact wires.
- They apply the necessary tensile loads to the catenary and contact wires. Fixed-anchored tension varies with temperature, whereas tension regulators apply a relatively constant tension in a regulated tension system.
- They hold the catenary and contact wires at predetermined heights above track, and usually about 3m off to the side of the track (on an anchor mast).
- In regulated OHW, a *fixed mid-point anchor* locks the catenary and contact wires from moving, which then forces the OHW to be properly regulated in both directions (towards and away from Sydney) without any wire drift. Therefore, these anchors do not take the full conductor tensions (they normally take only any out-of-balance tensions that would otherwise allow the wire to drift).

The anchor configuration usually includes a guy arrangement which transfers the tension loads in the conductors at their terminated height, down to the ground or some other nearby structure. The guy arrangement, if needed, forms part of the civil design for the anchor structure itself.

The boundary of what constitutes an *anchor* is given in *Figure 329*.

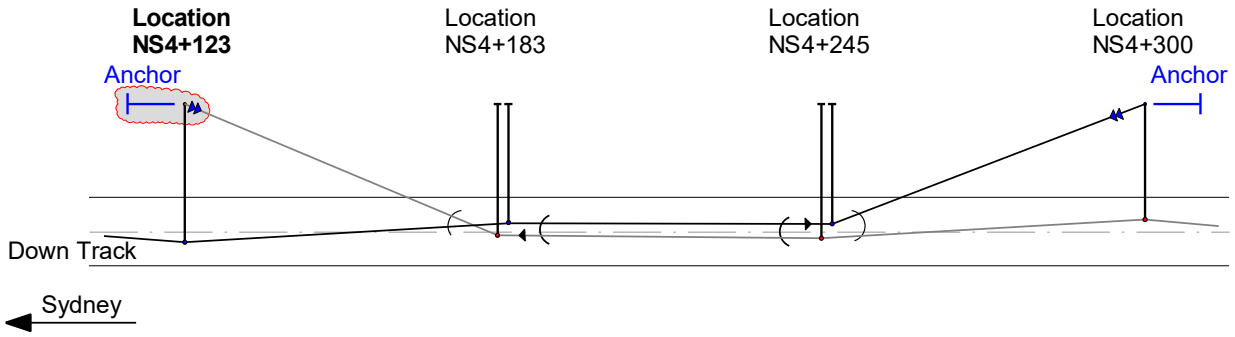
Properly tensioned OHW is of paramount importance for any OHW system that relies on tension. An entire run of OHW can be affected by having the wrong tension in the conductors. Improper conductor tensions can cause pantograph security issues, and can cause much distress to the operation of electric trains.

Anchor Arrangements

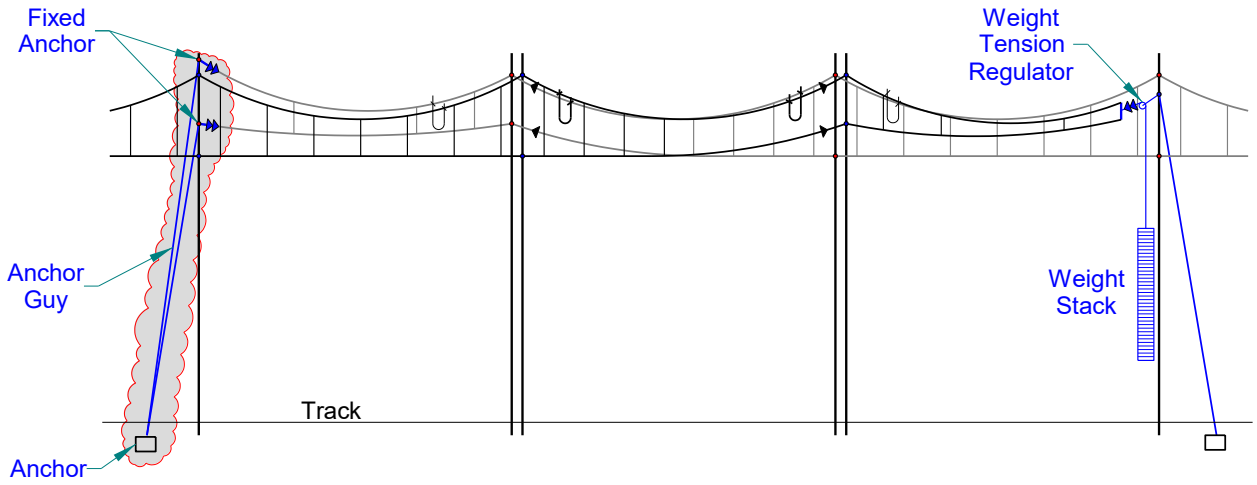
Anchor Arrangements

Asset
NS4+123, Down Track

Includes ...
Fixed Anchor
Weight Tensioner
Gas Tensioner
Spring Tensioner
Mid-Point Anchor



Top View



Front View

Figure 329 - Anchor Arrangements – boundary

3.4.0.3 Typical Components

The following components are common to most anchor arrangements:

- Termination insulators
- Conductor terminating clamps
- Turnbuckles
- Links, pins & shackles

Note that the anchor plates on masts (or walls, etc.), as well as the guy wire arrangement and guy blocks are all specified by civil design and installed by the civil discipline.

Various other parts relating to anchor arrangements will be discussed in subsequent sections.

ANCHOR BRACKETS

These mild steel brackets connect firmly to the anchor structure, which is normally a mast leg, or can be the face of a concrete structure or rock face. As mentioned above, this important bracket is designed & installed by the civil section.

From this bracket the various OHW components are launched, to eventually connect either the catenary or the contact wire, and allows these wires to be tightened to extremely high tensions in normal use.

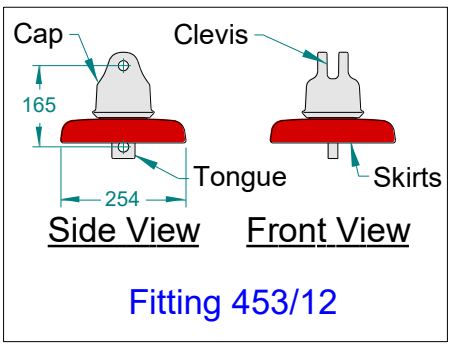
TERMINATION INSULATORS

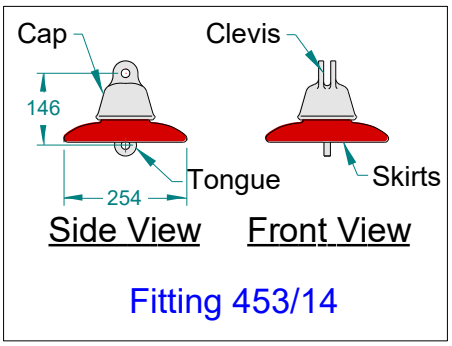
There are various approved insulators that are designed for insulating the terminated conductor at anchor locations. They need to suit the highest anticipated mechanical load and with the appropriate safety factor included. The insulation level needs to also be the highest in this "graded insulation" system (as discussed in *Section 5.1.7.2*, *Insulation Coordination*).

453/12 & 453/14 Disc Insulators

These are older 254mm (10") diameter porcelain insulators specifically intended for the termination of the OHW conductors (taking full in-line tension).

Note that any newer insulators use a grey porcelain instead of a browny/red colour.





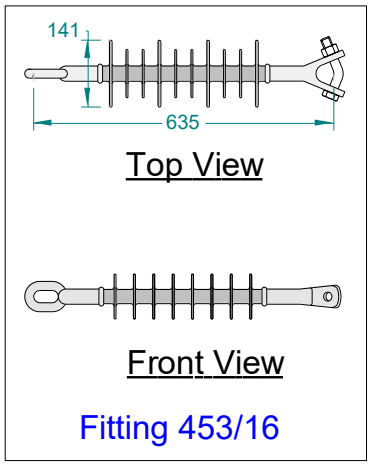
Aside:

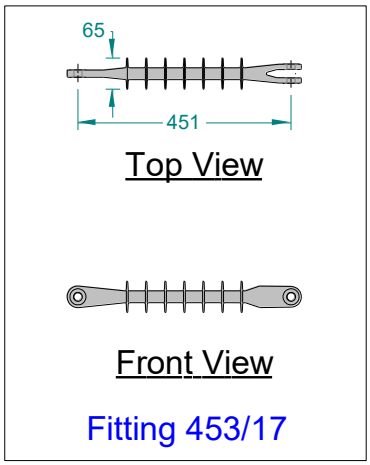
The 453/14 insulator was sometimes called upon to help improve a bay of extremely low contact height in fixed-anchored OHW (at hot temperatures). Here, the catenary height was raised by replacing the normal twin 453/13 catenary suspension insulators in series, (i.e. fitting 241/9) with this single insulator. This single insulator has better insulation properties, with its larger porcelain diameter of 254mm (compared with 190mm). This action effectively raised the contact wire about 146mm, and the mid-bay contact height was raised by half that amount (or the full amount if the same single insulator was installed at both ends of the bay). Note that this action was only accepted as a temporary fix.

453/16 & 453/17 Fibreglass Insulators

These newer insulators are made from a length of fibreglass rod, with numerous strands of glass fibre running from one end to the other and impregnated in resin. This configuration provides good tensile properties (to terminate the full conductor tension).

However, they are not good in bending or torsion, so have be installed with appropriate care.





Fitting 453/16 is a 120kN "*K-Line*" (Canadian) brand insulator, and is used to terminate catenary or contact wires up to 30kN (with the required 4:1 safety factor applied).

There are situations that require 2 such insulators to be installed in parallel in order to achieve the required safety factor (when more than 30kN is being anchored). *Example:* the tension regulator for 165mm² catenary / 193mm² contact using a single weight stack (providing 36.2kN of tension shared equally between catenary and contact wires), requires 2 × K-Line insulators in parallel to share the mechanical load (refer to *Figure 340* further on).

Important note:

Fitting 453/17, which is a 66kN "*Reliable*" brand insulator (US), is suitable for use as an out-of-running contact *pennant insulator* at an overlap, and has benefits due to its smaller diameter which are made from silicon rubber.

Unfortunately it is *not* suited for terminating at an *anchor* location. This is mainly because of its limited flashover rating to earth. (In the overlap situation, for the majority of its operating life, both sides of the insulator are at 1500V, giving about 0V across the insulator.)

Also, because of its lower tensile rating, it can only be used to terminate contact wire up to 16kN tension (with the 4:1 SF applied).

The 453/16 and 453/17 insulators had been type tested in the 1990s by the NSW railways. Both insulators passed the various tests, so they were included into the standard kit because of their various beneficial features. These benefits included lighter weight, no corrosion problems, no sharp edges when damaged (compared to chipped porcelain), the silicon rubber outer insulation cover is flexible, etc.

Note that type testing any proposed new 1500V insulator, and its ultimate approval for use, is mandatory in Sydney's OHW system. Such is the importance of these insulators to system reliability.

CONDUCTOR TERMINATING CLAMPS

These various clamps connect to the catenary or contact wire, and grip them in such a way as to not harm these copper wires, even when placed under the normal high mechanical tensions.

Clamps include:

- ***Catenary Clamp*** – this would be the *snail clamp*, the *preform wrap-on*, the *forked collar socket*, etc.
- ***Contact Clamp*** – this would be the *contact half-splice* or *forked collar socket*.

TURNBUCKLES

A turnbuckle is a device that can provide convenient adjustment to conductor tension in a fixed-anchored system (such as to anticipate and cater for conductor stretch), and it can also allow for conductor positional alignment relative to vertical alignment with other components.

It achieves length adjustment by the rotation of its body (by the installer) along the threads located on both ends of this slim device. One thread has the normal right-hand thread but the other has a left-hand thread, and this combination is the key to its ability to adjust its length through rotation. (One rotation gives a distance adjustment of twice the thread pitch.)

Turnbuckles for the tensioned catenary or contact wire normally have an adjustable length range from about 750mm to 1,190mm. For example, fitting 436/31.

The standard turnbuckles have clevis ends. Fitting 436/31 has 24mm holes for installation of 19mm SS pins or M20 bolts, as per the standard anchor arrangement drawings.

Because of the huge applied conductor tensions, there is generally no need to include lock nuts (which are typically included on turnbuckles for other applications in industry under lighter loads with vibration). No such lock nuts are provided with the standard turnbuckles.

LINKS

Links are used for separating a pair of insulators or providing appropriate mechanical connection in a certain configuration.

Links are typically made from mild steel flat, often welded to give some tongue & clevis attachment. Hole centres for connecting parts together are usually spaced 150mm apart, but other spacings do exist.

3.4.0.4 Configuration

The basic types of anchor arrangements are as follows (and detailed further in the below main sections):

- Fixed anchor (not to be confused with "fixed-anchored")
- Weight tension regulator
- Gas tension regulator
- Spring tension regulator
- Fixed mid-point anchor

Various other types of anchors have been tried around the world, including electrically motorised units installed in the tight confines of tunnels. However, the extra complexity may make them less reliable in the long term, and the ongoing maintenance costs must be substantial. But the real benefits of having regulated OHW inside a tunnel can be significant, especially if high speed trains are involved. (Sydney's system doesn't have high speed trains, so this is not such a problem.)

The simple tensioning devices listed above have mostly provided a high degree of reliability that's essential for an OHW system, and proven in Sydney over many decades. Of course, they still need to be maintained, but if properly set up, they usually perform well.

Note that the Gas and Spring tensioners are no longer used in Sydney's OHW system, but are included for historical purposes and because their characteristics may be interesting to some.

Figure 330 shows the typical makeup of a basic & simple ***fixed anchor*** arrangement, for terminating either fixed-anchored or regulated OHW conductors. It mainly details the guy arrangement.

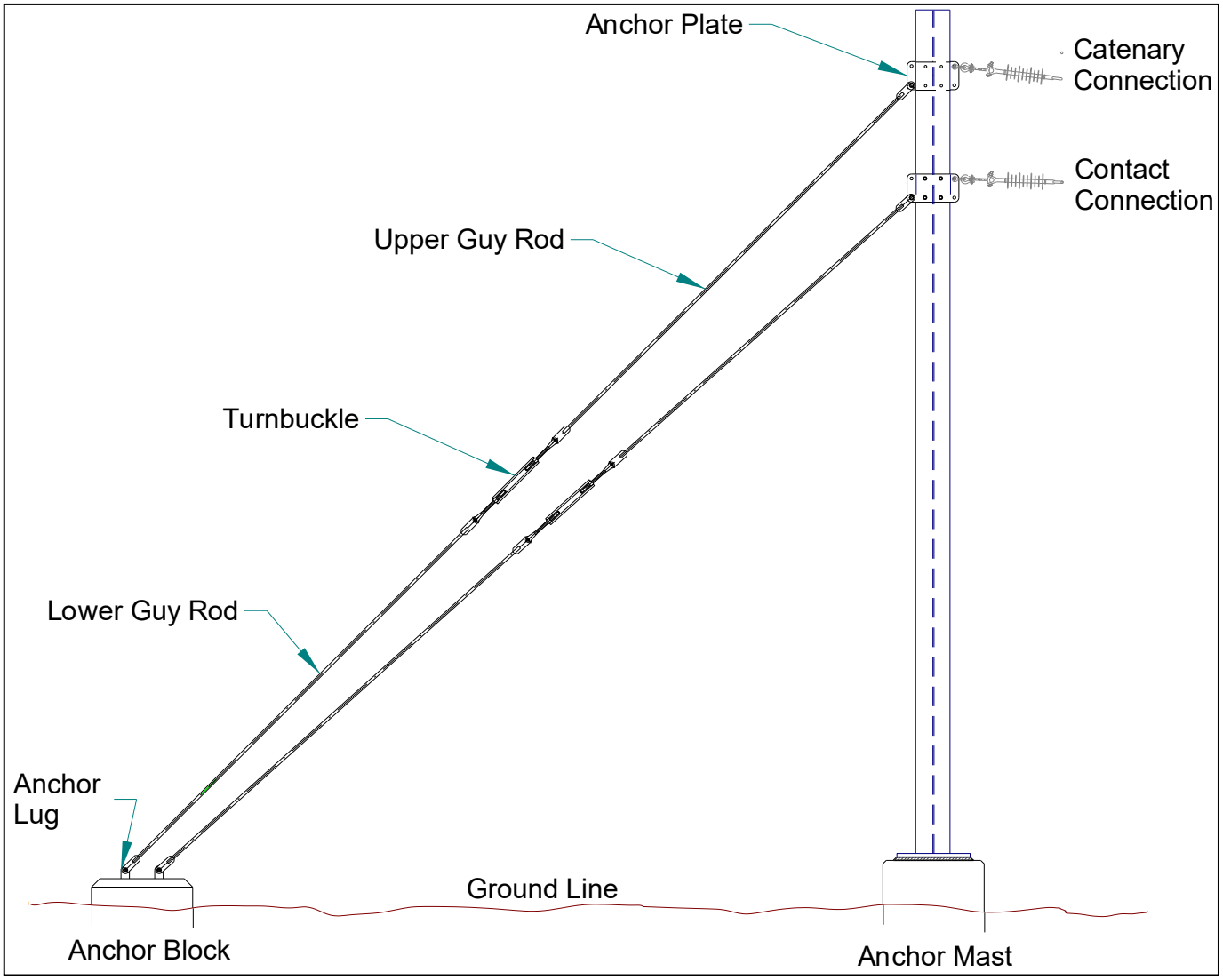


Figure 330 - Typical Guy Anchor transferring conductor tension to ground

GUY ARRANGEMENT

Most anchor arrangements require the conductor tensions to be transferred from a significant height (up to 7m or so above track level) down to a solid connection to ground or other structure. This requirement can be economically met using the guy setup similar to that shown in *Figure 330*.

As mentioned, the guy block, guys, anchor plates and anchor mast are all designed, supplied and installed by the civil discipline.

Usually the guys can be made from steel wires or steel rods, and are at about 45° to horizon. Having the guy wires installed at a steeper angle can reduce the amount of land occupied by this arrangement, however the steeper the guy wires the greater the tension in these wires, and there comes a practical limit as to how close to vertical they should become. At 45° angle, the tension in a single guy is 1.41× conductor tension.

Older guy arrangements used a stranded steel wire which returned around a small pulley (i.e. 2 guy wires down to the anchor block). This halved the required tension in the wire. Unfortunately, corrosion can take place between the stranding inside the wire and if it remains unnoticed, it can ultimately cause the wire to fail under its high load.

These days the anchor guys are generally made to drawing EL0237853, with one galvanised solid steel rod for each anchored conductor. The rods come in several standard lengths in

series and include a turnbuckle for distance adjustment. The rods have a welded clevis at one end and tongue at the other to allow ready connection – fittings 919/27 to 34 (the type of exposed weld allows easy examination for corrosion). The benefit of galvanised solid steel is that there can be no hidden internal corrosion. Also, a pair of shackles can be installed at one or both ends to provide some degree of rotational offset, if the mast anchor plate and/or the lug in the guy block do not line up (as detailed in the above drawing).

TMP Code	Equipment Name	Made By	Drawing No.
EP-08-21-00-00	**Anchor Arrangements**		
EP-08-21-01-00	*Liverpool-Glenlee Weight Tensioning Arrangement*	*RailCorp*	*C/77487 Sh. 4*
EP-08-21-11-00	*Standard Weight Tensioning Arrangement*	*RailCorp*	*A/80733*
EP-08-21-21-00	*Gas Tensioning Arrangement*	*(e.g.) A.P. Hydraulics*	*C/81304*
EP-08-21-31-00	*Spring Tensioning Arrangement*		
EP-08-21-41-00	*Fixed Anchor Arrangement*	*RailCorp*	*B/82418*
EP-08-21-42-00	*Contact Only Anchor*	*RailCorp*	
EP-08-21-51-00	*Regulated Tension Mid-Point Anchor Arrangement*	*RailCorp*	*A/86799 Sh. 1 (e.g.)*
EP-08-21-61-00	*Anchor Arrangement in Tunnels*	*RailCorp*	*C/25493 Sh. 1, 2*

Table 31 - Anchor arrangements

District	Approx. No. of Weight Tension Regulators *	Comment
North	783	
Central	672	
West	429	
Illawarra	738	
Total	**2,622**	

* As at end of 2013 – obtained from RailCorp Asset Explorer.

Table 32 - Weight Tension Regulator population by District (c. 2013)

3.4.0.5 Design Notes

DESIGN TENSION

The anchors need to allow the tension length of catenary and contact wires to operate within tolerance of their design tensions.

The main concerns with regard to tensions that are outside design parameters (for that particular OHW system), are listed below.

Effect on Catenary wire

- Too high a tension can cause the catenary wire and/or anchoring clamp components to become overstressed (especially if damaged in some way, e.g. corrosion), and they may ultimately break, causing the catenary to drop to the track.
- Too high a tension can reduce the electrical clearances to services located above the OHW. This includes overline bridges. Ultimately this may lead to flashover, damage to catenary strands, livening up the bridge, etc.

- Too high a tension in a fixed-anchored system can cause problems with pantograph interaction, as the resulting higher mid-bay catenary height pulls the contact wire up also, leading to successive bays of "hogged" contact wire. This can cause additional wear on the pantograph pivot components, as well as contact-to-pantograph arcing.
- Too low a catenary tension in a fixed-anchored OHW system can cause the mid-bay contact height to become too low when hot, which can ultimately result in the contact wire touching the roof of a train and thus interrupting train services. This can be a particular problem inside tunnels or under overline bridges in areas with already low contact wires.

Effect on Contact wire

- Too high a tension can cause the contact wire and/or its various clamps throughout the wire run to become overstressed and ultimately break, causing the contact wire to drop (although probably still supported by droppers from the catenary wire). Because the contact wire is a wearing component, any areas of reduced worn thickness throughout the wire run can more readily become overstressed to snapping point. This can be a significant issue to both regulated and fixed-anchored contact wires.
- Too low a tension can cause unacceptably large contact wire blowout with high wind speeds, especially at or near mid-bay. This can lead to loss of pantograph security, and if the pantograph does rise above the contact wire, this can result in many bays of damaged wiring, over a significant distance, until the train stops travelling or until the pantographs become demolished. Significant delays to services can ensue.
- Too low or too high a contact tension can affect the in-running to out-of-running contact wire profiles in an overlap bay, which may lead to arcing from pantograph, and/or the perception of an unsuitable overlap as fast trains pass through this bay.

Turnouts are one particularly vulnerable area, where the main OHW and the turnout OHW need to be in proper contact height alignment relative to each other at all times. Improper heights due to incorrect tensions can cause changes to the locations of forking-in points, and may ultimately cause the pantograph to snag an adjacent wire and start damaging things.

GUY ARRANGEMENT

Drawing EL0237853 was developed recently in 2011 to help standardise the guy rod arrangement and allow quick and consistent selection of appropriate length rods to suit each field situation.

There are 8 standard length guy rods which are colour coded for ease of identification. By using 1 or 2 of these rods in series, the total length of the arrangement suits a huge range of diagonal distances, from 3.75m to 12.35m – this is from anchor attachment point on mast down to the anchor block (refer to Setup drawing EL0083171). An adjustable turnbuckle helps achieve the correct overall distance needed to keep the anchor mast vertical.

TENSION LOSS

This is an interesting phenomenon that imposes a restriction on a ***regulated*** OHW system (but does not apply to a fixed-anchored OHW system).

Nothing's perfect in this world, and it would be nice if the tension in a regulated tension OHW system remained constant throughout the entire wire run.

However, in the real world the tension delivered to the OHW conductors by the tension regulator changes throughout the run, and it *deviates* the most at either the fixed anchor or at the fixed mid-point anchor location. The regulator is not the culprit here, as it delivers the correct tension (within tolerance) as required.

By Sydney's OHW design rules, in a regulated OHW system the maximum tension deviation from design – *tension loss* – at the fixed anchor, is set at ±10%. This comprises about 7% due to the cantilevers swinging with temperature, and about 3% for friction in the pulleys of the tension regulator arrangement. So, if the contact tension at the regulator is 18kN, the tension can actually be up to about 19.8kN or down to 16.2kN at the fixed anchor location.

Tension loss in the contact wire is more important than loss in the catenary, as the contact wire blowout is probably the main adverse outcome that needs to be controlled here. And the importance of this lower tension is likely the reason that the term "tension loss" had been used, rather than what I consider to be the more correct term of "tension deviation". (Of course the other adverse effect of swinging cantilevers is altered contact stagger, and this is dealt with in *Section 3.2.0.5,Stagger Change with Regulated Contact Wire*.)

Tension Loss Mechanism

The main variables that affect tension loss include:

- The *tension length* – the limit is about 1,000m from fixed anchor or FMP to the tension regulator.
- The *temperature* extremes – this causes the wire and thus the connected cantilevers to swing away from their "normal" position perpendicular to track. Of course, cold weather swings each cantilever closer to the fixed anchor and hot weather does the opposite. See *Figure 331*.
- The horizontal "*pivot distance*" from the cantilever pivot point near the mast out to the OHW conductors. The shorter this distance, the worse the tension loss. Mark-2 cantilevers on masts usually have a pivot distance of about 3m, while on drop verticals this can reduce to 2m or as low as 1.5m. The smaller distance values cause the tension loss to build up quickly at each successive cantilever location. A tension length will normally have a mix of these distances.
- The *track curvature* throughout the run – this translates to *radial load* exerted by the conductor on the cantilever back to the above pivot point. The higher the radial load, the greater the impact on overall tension loss, and the direction of the radial load is important.

Refer to *Figure 331*. This diagram shows a plan view of a cantilever arrangement, with support mast at top of diagram and OHW conductors (catenary and contact wires) at bottom.

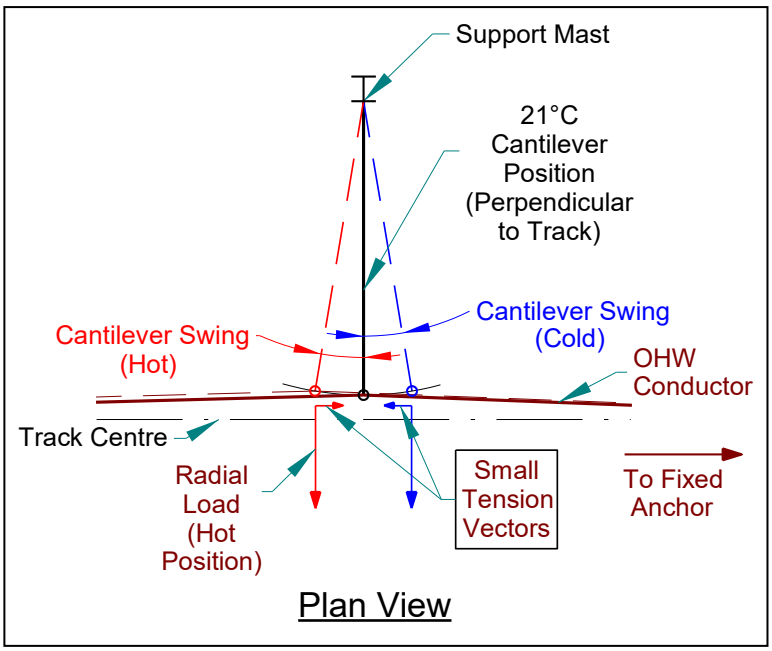


Figure 331 - Effect of Cantilever swing on tension

A cantilever installed perpendicular to track at the design temperature (21°C) does not affect the tension in these conductors. But as soon as the regulated wire and supporting cantilever swings in response to temperature change, a small load vector component is established, shown as "*Small Tension Vector*" in this diagram. The tension vector is in the direction that tries to bring the cantilever back to being perpendicular when the radial load is in the direction away from the mast.

This vector adds or subtracts from the conductor tensions at the OHW connection point. And it is always the bay closer to the fixed anchor that has its tension most affected by this specific cantilever location (the other bay is closer to the tension regulator and so its tension is marginally closer to the design value).

Example:

Figure 331 shows the situation when the wire is hot (in red). In this case, the wire is lengthened from the fixed anchor (at right), and so the cantilever swings away from the fixed anchor (to the left). The swung cantilever causes the small tension vector to be produced, which is proportional to the amount of radial load at this point (a higher radial load generates a higher tension vector). It is also a function of the amount of cantilever swing angle at that point – again, the higher the swing angle, the greater the tension vector. As mentioned, the radial load is trying to bring the cantilever back to being perpendicular to track.

The tension delivered to the wire comes from the left side (the tension regulator ultimately applies the tension), so this small vector load subtracts from the tension in the left bay, resulting in less conductor tension in the right-hand bay heading towards the fixed anchor.

Note that, if the radial load was in the opposite direction here (i.e. acting towards the mast, e.g. Type 2A cantilever), the tension vector would also be in the opposite direction and it would thus add, giving more tension in the right-hand bay, not less. It is this particular "negative radial load" situation that can sometimes cause cantilever instability problems in regulated OHW – see *Section 3.2.1.5*, *"Mark-1" Cantilevers*, *Type 2A Problems* for more.

Of course, the converse of this mechanism occurs under cold conditions (in blue).

If all successive cantilevers in a long wire run were configured the same as the above one, then there would be a reduced tension at the fixed anchor location when hot, and increased tension when cold – the *tension deviation*.

The amount of cantilever swing increases with distance away from the fixed anchor. So each successive cantilever swings a little bit more than its previous cantilever that's closer to the fixed anchor. The first cantilever out from the tension regulator has the maximum longitudinal wire movement and likely the maximum swing with temperature changes. (However, the amount of swing is also a function of the cantilever length from mast out to wire, with cantilevers installed on drop verticals delivering greater swing in this regard.)

On straight track, the stagger takes on a zig-zag pattern, and provided all cantilevers are installed on the same side of the track (as they usually are), this delivers a relatively small radial load and of alternating directions at each successive location. This situation effectively cancels any tension loss due to radial load.

Significant tension loss builds up on curved track where the radial load is in the same direction on successive cantilevers, and each one compounds the tension loss value. Tight track curves result in much higher radial loads, making the situation worse again.

There's the situation of a track going from one tight curve then transitioning into another but in the opposite direction (like an "S"). Here, when hot, the cantilevers swing in the same direction relative to their position normal to track So, provided all cantilevers have positive radial load (as they would typically do), then the tension loss would sum.

Ultimately, if each successive cantilever in the wire run adds a bit more to the tension loss value, then by the time the regulated tension is delivered to the fixed anchor, it will have been changed quite a lot from its design tension.

This is the cause of the tension loss, and its value for any wire run needs to be limited to less than 7% maximum.

Thus, the *tension length* has to be limited, due to the tension loss not exceeding this 7% value. This has economic implications when initially designing and constructing the OHW.

Practical Implications of Tension Loss

Generally speaking …

> Where the track is straight and then curved, tension loss is considerably ***less*** if the ***tension regulator is installed on the straight track*** portion and the ***fixed anchor is located on the curve***.
>
> So, the converse of this should be avoided, as it will likely give a much higher tension loss.

Refer to *Figure 332*, which shows the 2 situations stated above, with Case 1 good but Case 2 unacceptable. Of course, the real world has a mix of straight track and curved track of all sorts of radii along its route, and there are formulae that help determine and limit tension loss in this regard during the design process.

As mentioned above, there is virtually no progressive tension deviation (gain or loss) when the wire is installed from cantilevers for straight track. This is mainly because the conductor radial loads at each support & registration location are very small and alternate in their direction. However, on tight track curves, the progressive tension deviation is most prominent because of the very large conductor radial loads on the swinging cantilevers.

So, sometimes quite dramatic tension loss values can result simply by swapping the location of a moving anchor with a fixed anchor – contrast the 6% tension loss in *Case 1*, with *Case 2*, which has a totally unacceptable 15% tension loss, with both in the same physical situation but with "M" and "F" anchor positions simply swapped.

Example:

> I was once asked to review an external design proposal for new regulated OHW around Strathfield Triangle – including the extremely tight radius single track joining the northern tracks directly to the western tracks. The initial design had a tension regulator (at one end of an overlap) installed on the tight radius for a distance, and the fixed location on the northern corridor among relatively straight track. Um ... I asked for the "*tension loss calculations*" to prove the design would work, and was soon given a new proposal which had the anchors swapped (I think the tension loss would have been near 20% !).

The calculated tension loss should ideally be shown (in %) on the *tension length diagram* for any new project, to confirm that this tolerance has been checked out and that it doesn't exceed the maximum 7%. When the design is approved, this information should ideally be transferred to the approved OHW layout at each fixed anchor or fixed mid-point anchor location (next to the tension length/s numbered in metres) for future reference.

An old, rough "rule of thumb" was that you could expect to have about 15 cantilevers supporting wire from the tension regulator to the fixed anchor or fixed mid-point. The Design Office has used a formula with a bit more precision than that, but the end results are usually similar. There are other more complex formulae available that can more accurately predict the amount of tension loss, but it's not covered here.

The bottom line is that the OHW tension lengths can be maximised by judicious placement of the Fixed and Moving anchors. This can result in less equipment (fewer overlaps and anchors) which reduces both the cost of initial outlay and maintenance costs into the future.

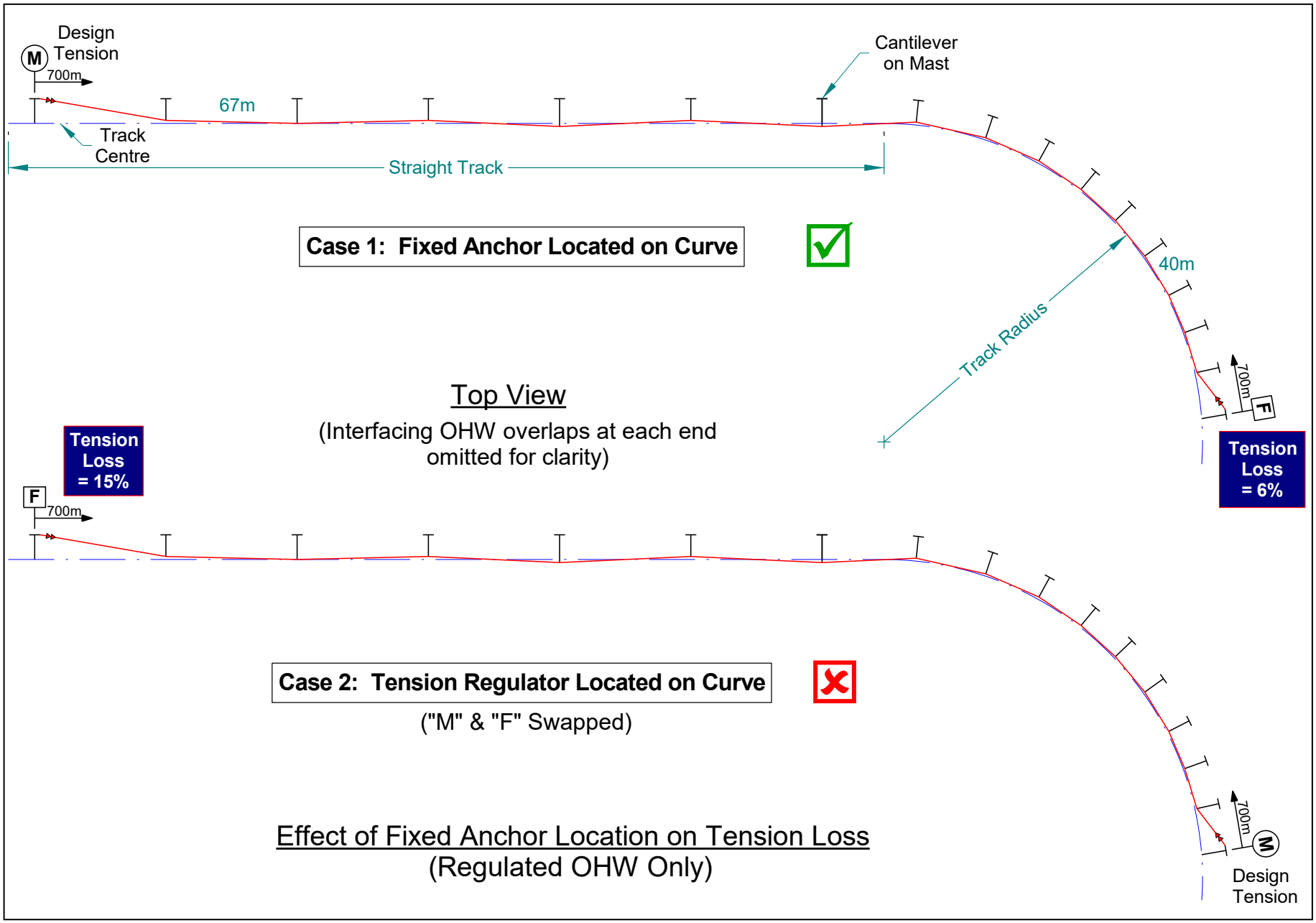


Figure 332 - Effect of Fixed Anchor location on tension loss

3.4.0.6 Status (c. 2014)

- ***Spring tensioners*** are being removed from the electrified system, and are not to be installed (they're likely all gone now).
- ***Gas tensioners*** were removed from the system in 2010. They are only to be used where they can be justified, and only with formal approval (due to their higher maintenance needs).
- ***Stranded steel guy wires*** are no longer being used – the current standard is solid steel (galvanised) guy rods. Existing stranded guys should be replaced with solid arrangements.

3.4.0.7 Reference

Refer to the above *Table 31* for relevant drawings.

3.4.1 Fixed Anchor Arrangement

3.4.1.1 Description

A "fixed anchor" appears as a set of conductor termination insulators and associated hardware attached to an appropriate anchor location, such as a mast, bridge steelwork, bridge face or underside of tunnel, etc.

Refer to *Figure 333* for one of the fixed anchor arrangements (for a single catenary / twin contact OHW system).

It is the most simple and basic form of anchor. It's used in a fixed-anchored OHW system at both ends of a wire run, and is also used in a regulated OHW system at one end of the wire run.

Anchor masts generally have some form of guy arrangement to transfer the significant load to ground.

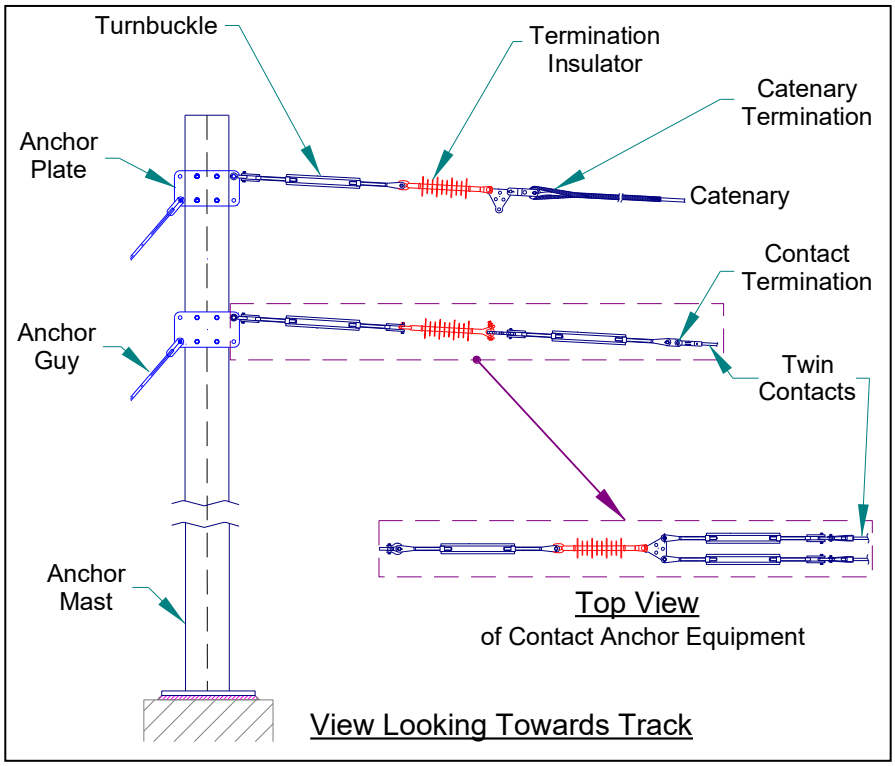


Figure 333 - Typical Fixed Anchor & components

3.4.1.2 Function

The fixed anchor terminates the OHW conductors and provides a means of "fixing" the position of these conductors from moving under applied tension (thus the term "fixed").

3.4.1.3 Typical Components

These include:

- Anchor insulators (for primary insulation).
- Conductor termination fittings and connecting pins.
- Anchor plates for attachment to the anchor structure.
- A turnbuckle is sometimes included for tension and/or wire position adjustment.

3.4.1.4 Configuration

The *fixed anchor* can be used:

- In a *fixed-anchored OHW system* (at both ends of an OHW tension length), or
- In a *regulated OHW system* (at one end only of a tension length and with a tension regulator installed at the other end).

Referring to *Figure 333*, the termination of the OHW through insulators needs to be made to an anchor plate that's designed to transfer the mechanical loads appropriately to the final structure taking these loads (such as an anchor mast, or bridge face, or rock, etc).

There are 2 anchors – catenary and contact – on the anchor mast in this figure. Note that the 2 anchor plates are bolted onto opposite flanges on this mast (contact anchor on the closest face to the track to reduce contact radial loads, and catenary anchor on remote face). This is done to help balance the resulting load on the UC mast, so that it doesn't twist excessively. (Quite often an OHW cantilever is also installed on the anchor mast to support the in-running OHW.)

Turnbuckles are typically employed in the fixed anchor arrangement. They allow some limited degree of position adjustment, either to align fittings (e.g. catenary and contact insulators to be vertically aligned) and/or to provide some amount of tension adjustment (in a fixed-anchored OHW system only).

"AS" ANCHOR STRUCTURES

The early fixed-anchored OHW systems used to rely on two "'AS' Anchor Structures" to terminate the out-of-running catenary and contact wires – these structures were installed at each end of the single overlap bay. Refer to *Figure 326* further back. (I assume the "AS" abbreviation stands for Anchor Structure.)

There are a few benefits to come from using this structure.

- It allows the out-of-running catenary & contact wires to be directly terminated, meaning an overlap can take up 1 bay (the overlap bay) instead of the usual 3 or 4 bays (with pennant wires going to anchor). The anchor points for both catenary and contact wires are usually located directly above the track being serviced (with suitable staggers), and typically 2 tracks are involved. This was particularly beneficial in 4-track situations, as there are no anchor pennants involved (which for the centre 2 tracks may otherwise involve at least 2 bays each side of the overlap bay to eventually anchor to ground, i.e. 5-bay overlaps).
- This structure doesn't require anchor guys to transfer the terminated conductor anchor loads from leg down to ground. This makes it a relatively compact form of anchoring in terms of occupied ground space. (There's no need for both the anchor block located up to about 8m behind the anchor structure leg, and the accompanying long guy wire/s installed at 45° down to ground.)

However, there are some drawbacks as well when using this structure.

- If used in an overlap, the anchor points and in-running catenary support points need to be well located, as there's little provision for lateral position adjustment (and the staggers in an overlap bay need to be set reasonably accurately).
- This structure is often highly loaded, because it needs to handle the mechanical loads of 4 runs of OHW conductors at an overlap (assuming twin tracks). It needs to anchor 4 *terminated wires* onto the portal bridge, support the various weight loads of 4 OHW runs, and handle the catenary and contact radial and wind loads for these 4 runs.
- As can be seen in *Figure 326* further back, the *in-running catenary* wires are trapped inside the latticework of the bridge. Not only is the catenary difficult to install (requiring it to be threaded through the structure), it also needs to maintain electrical clearances in all directions to the surrounding steelwork in quite a confined space, throughout its operational life.

For more details on these structures refer to *Section 3.3.3.4, "AS" Anchor Structure*.

TUNNELS

Inside the confined space of a tunnel, simple steel brackets attached to the tunnel lining are used to anchor each wire, usually somewhere near the crown of the tunnel (there is normally no need to bring the wires off to the side of the track to anchor them). These anchors can be installed for establishing overlaps or at the ends of crossover runs.

Because the contact wire is lower and therefore takes longer to rise, its anchor is usually located well after the catenary wire is anchored, often by almost a full bay.

So, this often leads to an overlap of 3 catenary bays and 5 contact bays (see below).

Alternatively, if there is sufficient vertical space, both wires can be anchored on the same bracket, as shown in *Figure 334,* which is a high flat ceiling situation at Chatswood (RES).

Figure 334 - Anchor bracket installed on ceiling

Figure 335 shows a situation in a single-track circular bore tunnel.

The anchors here are longitudinally separated by a few metres, which allowed both anchor insulators to align vertically with each other.

Figure 335 - Catenary & Contact Anchors (Epping to Chatswood tunnel)

Figure 336 shows the design profile drawing of an overlap in the Airport Line on the country-side of Domestic Station. This drawing shows the conductor profiles at the design temperature (25°C). As part of the design process, it had also been checked out for suitability under the temperature extremes at this location inside the tunnel, and the corresponding profiles show quite a dramatic difference to the design profile shown here.

This overlap has the more typical overlap configuration of 3 catenary bays and 5 contact bays from anchor to anchor.

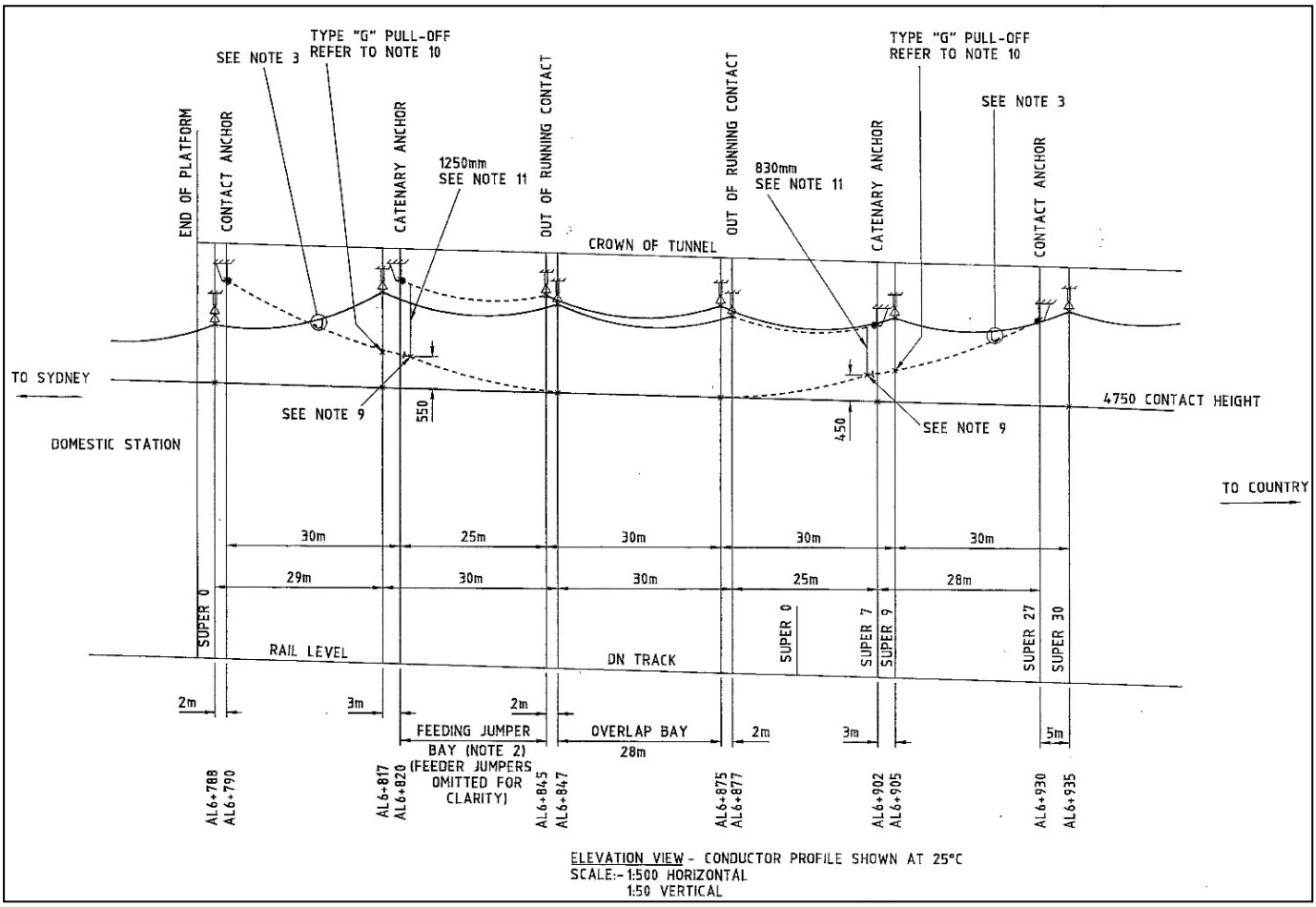


Figure 336 - OHW Overlap profile in Airport Tunnel showing Anchor locations

3.4.1.5 Design Notes

TURNBUCKLES

There are 3 turnbuckles used in the twin contact anchor arrangement shown in *Figure 333*. I think the need for all 3 comes about when used in a fixed-anchored OHW system – the turnbuckle is provided primarily to adjust the conductor tension, which is an important requirement (needed during maintenance, especially to regain tension if wire creeps over time).

The turnbuckle closest to the mast offers overall wire tension adjustment (the same applies to the catenary anchor arrangement above). Because it's a twin contact system, there is also the need to adjust each contact position and/or tension individually.

TENSION LOSS IN REGULATED OHW

In regulated OHW, the maximum tension loss occurs at a fixed anchor or fixed mid-point location. See *Section 3.4.0.5*, *Tension Loss* for more information.

3.4.1.6 Status (c. 2014)

Because of their simplicity, most styles of fixed anchor arrangements are generally suitable.

3.4.1.7 Reference

See *Table 31* for drawing reference.

3.4.2 Weight Tension Regulator

3.4.2.1 Description

Currently, each "weight tension regulator" appears as a stack of flat cylindrical cast iron weights on a support rod, installed next to a mast or portal leg or sometimes on a wall. The attachment height is roughly the catenary height (~7m) or contact height plus a bit (~5 to 6m), depending on the conductor being anchored. *Figure 337*.

Figure 337 - Standard Weight Tensioners

Multi-stranded, flexible steel wire rope connects to the top of the rod that supports the weight stack, then runs vertically up, passes around 3 pulleys located above the weights, and finally connects to the side plates of the furthest pulley.

This furthest pulley is mechanically attached to the OHW conductor or conductors through termination insulators – this connection ultimately tensions the OHW conductor/s.

There was an earlier weight tension regulator arrangement developed and used only in the "Liverpool to Glenlee" project. This tensioner is quite different in appearance, as the weights are trapped within a special mast (acting like a cage), and the pulleys include a special "ratchet" mechanism (described further on).

3.4.2.2 Function

The weight tension regulator applies a constant and relatively accurate tension to the OHW conductors, irrespective of conductor temperature.

It is a relatively simple but reliable device that, in essence, relies on the mass of a stack of weights and 3 pulleys to deliver 3 times that mass as tension into the attached conductor or conductors.

Any extension (when hot) or contraction (when cold) of the copper conductors is taken up by the weights moving down or up the anchor mast (respectively), thus ensuring a fairly constant design tension in these conductors.

The weights move vertically 3 times the amount that the wire expands or contracts with temperature change. So, there needs to be adequate vertical space for the weights to move vertically, unimpeded under the temperature extremes.

The tension can be applied to a single conductor. Alternatively, an "equalizer bar" (or "yoke plate") can be installed to transfer the weight-generated tension across to both the catenary wire and contact wire (with normally half the total tension delivered to each wire). It can also divide the tension between 2 catenary wires (in the case of a twin catenary OHW system) or 2 contact wires (if it's a twin contact OHW system).

3.4.2.3 Typical Components

The main components are described below.

WEIGHT STACK

The weight stack comprises the required number of cast iron weights resting on a long vertical galvanised steel support rod.

The individual weights these days have a mass of 25kg ± 0.5kg and are 320mm diameter and 47mm tall. The weights are galvanised to prevent corrosion, and importantly this in turn helps to possibly identify any internal corrosion (shown up as brown on the weights), especially at the base of the highly loaded support rod.

Figure 338 - A pallet of Weights

A slot in the design of the weights allows them to be installed directly onto the support rod. Refer to *Figure 338*.

Each weight has a square recess in the bottom and an equivalent raised section on the top. So, the recess of one weight interlocks with the corresponding raised portion of the next lower weight to help keep them locked together. In doing so, it helps the weight stack to act as one unit. The slot in each alternate weight is rotated 180° – seeing alternate slots helps when counting the number of weights installed (counting pairs of weights is easier, to confirm the correct number is installed for delivering the correct tension).

One of the weights includes a drilled and tapped hole for attaching a special *eye bolt* (with lock nut). This eye bolt is captured on the vertical guide rod attached at top and bottom to the anchor mast, which helps to control any swaying movement of the weights, e.g. under windy conditions.

PULLEYS

Each of the 3 pulleys is 250mm in diameter and made from galvanised cast iron.

To minimise friction, each pulley rotates on its axle through a pair of taper roller bearings, and the hub that contains these bearings is packed with grease for long term lubrication and to minimise internal corrosion.

The bearing assembly is sealed from moisture ingress by neoprene seals.

More details, including diagrams and photos, as included in *Section 3.4.2.4*, *Tension Regulator Pulley*.

WIRE ROPE

The wire rope connects the weight stack to the pulleys that ultimately tension the OHW conductor/s.

This rope is typically 14mm diameter, with a fibre core and 216 strands of hardened steel, and each strand is galvanised to prevent rusting.

The stranding size and pulley diameter are jointly designed to prevent fatigue of the wire as it passes around the pulleys.

SIDE PLATES

A steel plates is located on each side of the pulleys to trap them and help mechanically connect the pulleys to other parts. These can be seen in *Figure 339*.

TERMINATION INSULATORS

Enough said already.

EQUALIZER BAR (YOKE PLATE)

This simple device apportions the anchored tension between 2 conductors, usually in equal measure. See *Figure 340*. It is less commonly used these days.

This bar is normally made from 75mm × 20mm section steel, about 450mm long and is galvanised. The holes are usually equally spaced about a centre pivot hole to provide equal tensions to both catenary and contact wires.

This fitting is used to deliver tension to both the catenary and contact wires at a common anchor point, and normally the tension is split equally between these conductors. An example is the Gosford to Newcastle OHW system which has 16.5kN tension in both the catenary and contact wires, and this is from a tension regulator that generates 33kN tension.

Note that there have been some equalizer bar designs that are now no longer used because they do not reliably deliver the required tensions all the time – refer to *Section 3.4.2.5*, *Equalizer Bar & Problems* for further information.

ANCHOR PLATE

This thick steel plate connects the tension regulator to the anchor mast or structure.

GUY ARRANGEMENT

This consists of steel wire rope (the old approach) or steel rods, often inclined at 45° to the ground, which transfers the conductor mechanical tension loads down to ground.

GUIDE ROD ASSEMBLY

The guide rod is a vertical steel pipe, with end connectors that attach it to the anchor mast. The connectors include provision for adjustment to help make the rod vertical and locate it a short distance from the anchor mast and in a direction that's compatible with the natural hanging position of the weights (which align with the conductor direction).

The standard guide rod is galvanised steel tube with an outside diameter of about 27mm, and its length is 3,450mm. One rod is needed for each weight stack.

Figure 339 - Tension Regulator viewed from above

An eye-bolt in one of the weights of the weight stack attaches to this rod, allowing it to travel up and down as required. This helps keep the weights located close to the anchor mast (especially in windy conditions).

Figure 339 is a view from on top of a tension regulator arrangement (installed at Central Flyunders). This shows the weights with eye-bolt guiding them on the guide rod.

3.4.2.4 Configuration

Note that *Section 4.2.2, Anchors* contains some history of the development of the tension regulators dating back to the 1960s to 1990s for Sydney's OHW.

Regulated tension is achieved by using a set number of appropriately sized weights whose mass moves up and down beside the anchor mast in response to changes in conductor wire length, due in turn to copper expansion or contraction with conductor temperature.

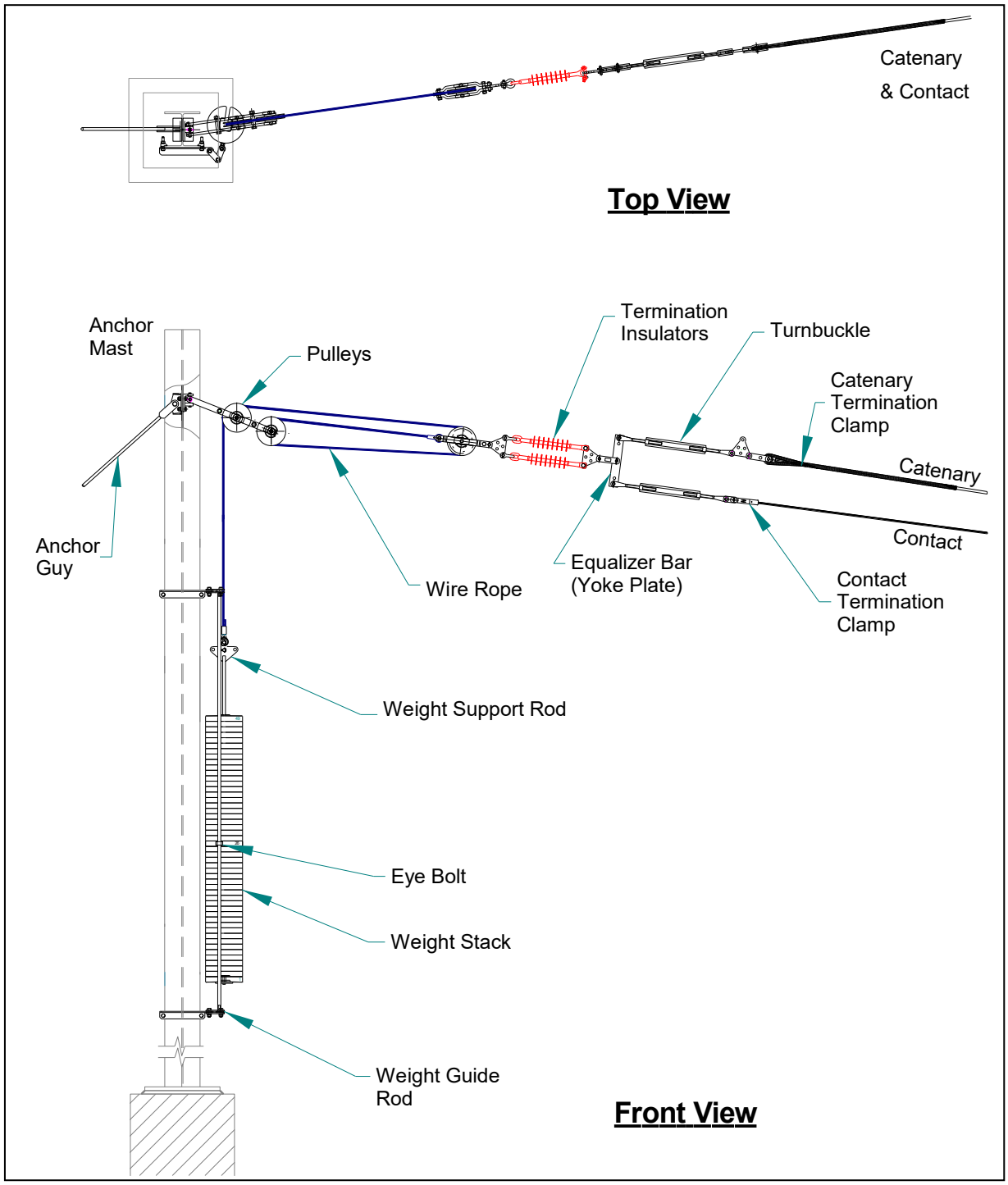


Figure 340 - Standard Weight Tensioner arrangement

This arrangement can achieve quite accurate tensions (typically within 3% of the design value). It is also relatively simple to maintain, giving confidence that it's doing its job, and is also quite reliable in operation.

Figure 340 is a drawing of the tension regulator for 165mm² Catenary / 193mm² Contact, with the equalizer bar to deliver equal tensions to each conductor from a single weight stack.

Figure 341 is a drawing of the standard 270mm² Catenary / 2x137mm² Contact regulator.

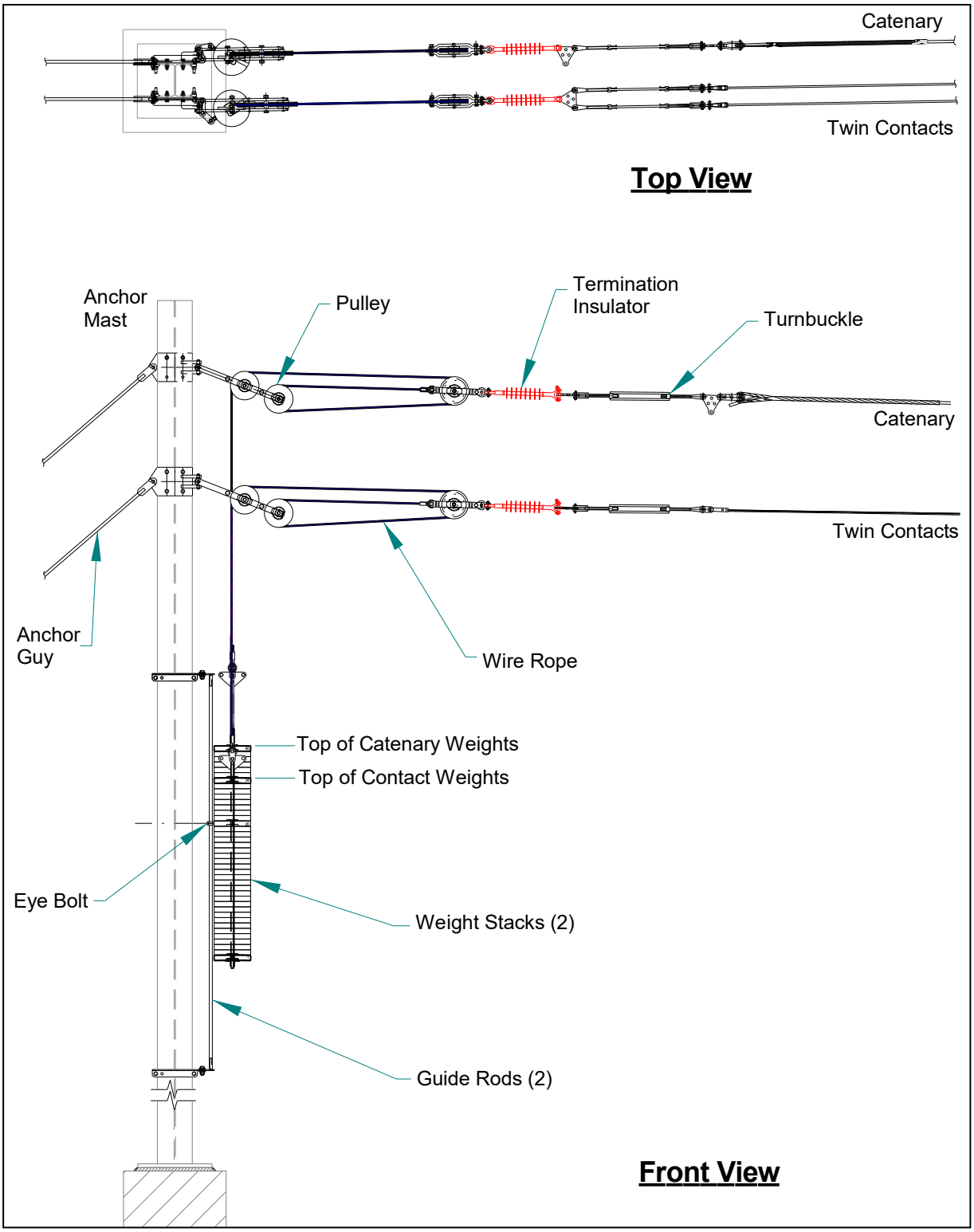


Figure 341 - Twin Tension Regulator on a single Mast

The total mass of the weight stack is calculated by multiplying the mass of each weight by the number of weights, then adding the mass of the weight support bracket (which has been assumed to be about 1 additional weight). So, the total tension delivered to the OHW conductors is this weight stack mass multiplied by 3, because the 3 pulleys provide a 3:1 mechanical advantage.

The down side to the mechanical advantage gain (above) is that the vertical movement of the weights is 3 times the amount the OHW conductor extends or contracts in response to temperature changes. For example, the tension regulators are designed for a nominal temperature range of -5°C to 60°C, so a 1,000m length of wire will expand by 1,105mm for this 65C° temperature change. This means the weights will move vertically by 3 times that figure, i.e. 3,315mm, which is a rather large distance.

The anchor height thus needs to be high enough to cope with the length of the weight stack plus this movement.

The 3:1 pulley advantage is well suited to the conductor tensions and anchor heights in Sydney's OHW system. Indeed, the wire rope has suitable passing clearance (of about 50mm) between the top of the 2nd pulley and the rope above, thanks to the mass of the weight stack lowering the angle of the side plates that connect the 1st and 2nd pulleys to the mast.

If 5 pulleys were used (as sometimes seen in 25kV systems), the 5:1 pulley advantage would require fewer weights (i.e. tension / 5) giving a smaller weight stack height, but would also require 5x the change in conductor length as vertical weight movement up and down the mast, which is likely impractical with Sydney's large conductor tensions.

In the example above of 1,000m wire length and 65C° temperature change, this 5-pulley system would require a vertical weight travel of 5,525mm plus the height of the weights. This in turn needs an anchor height well above contact height (more likely catenary height), which is no good. Also, the existing system of 3 pulleys has the same pulley diameters, however with 5 pulleys, the diameters need to change for gaining clearance from wire to nearby pulley wheels, and this tends to complicate things. But the wire rope diameter could be smaller, which is a good thing.

If Sydney's conductor tensions were significantly lower, a smaller stack height may have been achievable and the 5-pulley scheme may have been possible. Alternatively, higher anchor heights would be needed – somehow.

The tension delivered to the OHW conductors also depends on the number of conductors being tensioned by the common weight tensioner. One weight tensioner connected to a catenary delivers all its tension to that catenary. However, if a common weight tensioner connects to the catenary and contact wires, the tension from the weights is shared between these conductors. The amount of sharing depends on the geometry of the equalizer bar (yoke plate), which is used to connect the tensioner to the catenary and contact wires. In most situations, the equalizer bar is designed to share half that tension equally to catenary and to contact wires.

Example:

> In the previous example of Gosford to Newcastle Electrification, the tension regulators used a single weight stack of 11kN (1.1 tonne), which delivers a total 33kN to the conductors, and the equalizer bar then shares this as 16.5kN (1.65 tonne) in catenary and 16.5kN in contact.

Weight tension regulators normally have one of the following configurations:

- A ***single weight tensioner*** is attached to both catenary and contact wires using an equalizer (yoke) plate. The catenary and contact wires share the total tension provided by the weight tensioner.
- A ***pair of weight tensioners*** is located on opposite sides of a single anchor mast – one set tensions the catenary wire/s, and the other tensions the contact wire/s. A single catenary receives the full tension from its regulator. Likewise, a single contact wire receives the full tension from its regulator. But with twin contact situations, each contact wire gets

half the total regulator tension (through its own type of equalizer bar). The same applies to twin catenaries.

- A ***single weight tensioner*** is installed on a single anchor mast tensions the catenary only, and another weight tensioner on a *separate anchor mast* tensions the contact wire/s. Anchor masts are displaced longitudinally by 3m or so, e.g. *Figure 540* much further on.

Of course, the above scenarios could be installed on a wall instead of a mast, and the wall would need to handle the huge pull-out load of the conductor tensions, and the weight of the tension regulator weights.

Weight tensioners installed on masts or portal legs, require their section size to be strong enough to suit the additional compressive load of the weights, as well as the anchor guy load to ground (and any other OHW support & registration loads located on the same structure).

TWIN WEIGHT STACKS

The current principal OHW system is a single catenary / twin contact regulated system, and there are 2 tension regulators needed for this – one to tension the catenary and one to tension the contacts. The weight stacks usually sit side by side on an anchor mast.

Ideally the bottom of the both weight stacks should be installed at the same common level. This policy allows maintenance workers to determine if there's a likely problem if and when the stacks suddenly don't line up. (The tensioned lengths of both catenary and contact wires are normally similar, e.g. 800m, so the weight stacks should move up and down together in unison as temperature changes.)

In this way, things like contact wire stretch over time can be detected when there's a distinct difference in the bottom level of the weight stacks (the stack tensioning the contact wire should be lower if contact wire stretch is the culprit).

TENSION REGULATOR PULLEY

In recent times, the cast iron pulleys have had 2 holes drilled at right-angles to each other in the web – refer to *Figure 342*. This was not an attempt to keep the weight down – it was done so that the maintainer could tell from the ground whether the pulleys were rotating and thus their roller bearings had not seized, and so the regulator was likely performing as intended. Seized bearings mean that the OHW conductors perform as a quasi-fixed-anchored system which, for a system designed as regulated, could lead to disastrous consequences.

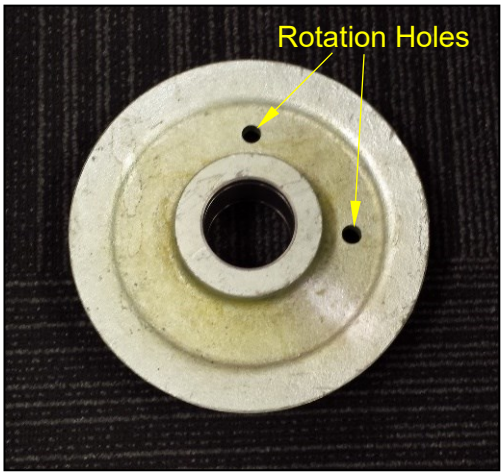


Figure 342 - Typical pulley wheel

The idea with the holes is that you should always be able to see at least one hole, even if the other hole is covered up by the side plates. If you note the position of the hole, then come back later in the day when the temperature had changed, you should see that the position of the hole has changed. If the position hadn't moved, then this could indicate a seized bearing, which should prompt closer scrutiny and maybe the replacement of the pulley itself. Refer to *Figure 343*.

Unfortunately, it seems that many pulleys have no such holes and so there's no physical reference by which to judge this relative rotational movement.

Also, if the pulleys seize but their axle rotates in the side plate holes, then this can give a false indication. In this case there should be an indicator on the ends of the axle pointing down (for instance) to show the axle isn't affected. Unfortunately (or should that be fortunately) the

axle cannot be locked to the side plates with the current design.

There are no guarantees with this overall method, but it's much better than doing nothing.

Figure 343 - Catenary (upper) & Contact (lower) tensioner pulleys

The pulley hub contains 2 tapered roller bearings, shims, 2 oil seals and circlips.

Figure 344 shows a completed bearing assembly on its axle (top diagram), and one side dis-assembled showing most of the parts, especially the tapered roller bearing (bottom diagram).

The assembled bearing fits neatly inside the lathed hub of the cast iron pulley wheel. The 2 circlips fit into grooves lathed in the hub to trap the assembly inside the hub.

The hub space is packed with grease during the assembly. Grease helps reduce friction and wear, and also helps prevent corrosion if moisture enters the hub, e.g. due to damaged oil seals.

UV light tends to accelerate the ageing of the neoprene oil seals, and if the rubber perishes it can then let moisture in, which can then cause corrosion of the roller bearings. I have seen corroded bearings where all that was left was a black powder and a few iron filings, although it was thought that this may have been accelerated by the molybdenum disulphide grease used back then.

Figure 344 - Wheel bearing assembly

Special stainless steel shields (fittings 601/98 and 99 – *Figure 345*) were introduced in 2006 in an attempt to significantly reduce the direct exposure of UV radiation from the sun onto the oil seals so as to extend their life. The shields are a retro-fit item that can be easily installed. However, I had observed that many of the regulator pulleys in the field were still without these shields, which would likely be a costly mistake in the long run.

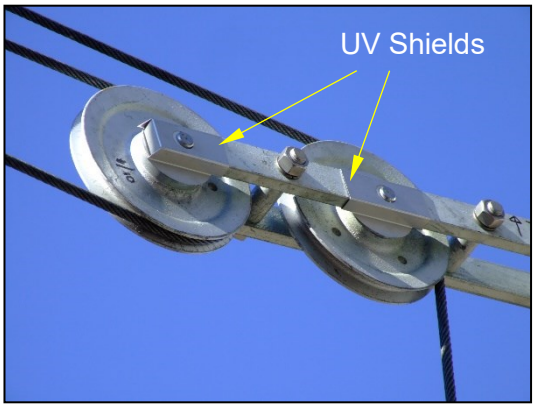


Figure 345 - Stainless steel UV shields

The manufacturing details of the current tension regulator pulley are shown on 2 related drawings:

- EL0442180 – shows the general arrangement and configuration of parts – see *Figure 348*.
- EL0442181, which describes the special step-by-step instructions that should be closely followed when assembling each pulley.

THE "WEIGHTSET" PROGRAM

For a set of weights to properly tension the wires, the weights must not be impeded from free upward and downward movement next to the anchor mast. In fact, there are 3 aspects that should be checked out, leading to ***5 critical clearance conditions***, as shown in *Figure 346:*

1. The weights must not:
   (a) Jam against the pulleys under cold temperatures, nor
   (b) Bottom out to ground or other obstruction (e.g. signal or HV troughing) when hot.
   See "A" & "B" dimensions on the diagram.
2. The guiding eye-bolt installed in the weight stack must not jam against:
   (a) The upper or guide rod bracket under cold temperatures, or
   (b) The lower guide rod bracket under hot temperatures.
   See dimensions "C" & "D".
3. The distance between the 2nd and 3rd pulleys must not be less than about 700mm (horizontally) under hot conditions. See dimension "E".

The 5 conditions – 1a, 1b, 2a, 2b and 3 – need to pass for the tensioner to function properly.

An Excel spreadsheet program called "WeightSet" was developed in 2009 to accurately model 1 or 2 sets of weight tensioners installed on an anchor mast. (The 2 sets is only for the case of a common twin weight tensioner that's tensioning the catenary and contact wires separately for the same wire run, which is the most common arrangement these days.)

Up until 2009 there was a fair degree of guesswork involved in determining the correct height to install the weights and associated guide-rod brackets, to suit the temperature at the initial setup. At first glance it appears to be quite straightforward, but it's actually a complicated situation with lots of variables that come into play. Also, the position of the weight stacks needed to be periodically checked during their maintained life to ensure that, with any progressive wire stretch, mast movement in ground, etc., the weights would not result in any of the 5 conditions (above) being progressively breached.

The ***WeightSet*** program accurately models each tension regulator, with all vital parts drawn to scale (pulley diameters and their spatial positions, lengths of wire ropes when standardised, weight support rod lengths, weight stack dimensions, guide rod attachment heights, anchor heights, etc.). Various standard items can be easily selected by drop-down lists.

So, it delivers true dimension-driven results based on the many input variables, that then allows an accurate assessment to be made *with confidence*.

But I think the real strength of this program comes from the Excel "chart" that it draws to accurately show a "picture" of the tension regulator/s under temperature extremes. This picture (along with the supporting numbers in the spreadsheet cells) then allows us to better understand what's going on at a glance, and more importantly, what to do to correct any problems with impeded movement.

Refer to *Figure 347* which shows a typical example of the WeightSet program output, with a pair of tension regulators installed on an anchor mast. The left half of the WeightSet output sheet has the details of the weight tensioner/s and the right half has the corresponding chart (picture). Of the left side, the top third contains "Design Information" for the weights, then below is the "Initial Construction Setup" (for use when initially building the arrangement/s), then under this is "Field Check When Installed" (to be used when finally installed, and for subsequent periodic maintenance), then "Guide Rod Assembly" (which is also referred to during construction and when maintaining the arrangement/s).

This diagram displays the range of weight stack vertical movement corresponding to a long 950m tension length of wire for OHW System 2. (Note that the longest weight support rod and its weight stack occurs with the twin 270mm² catenary stack of OHW System 12.)

This particular example displays a problem with the contact tensioner. The eye-bolt installed in the weight stack bottoms out on the lower guide rod bracket – see the "-11mm" entry in red background. This means the lower bracket (and linked top bracket) need to be shifted at least 11mm lower (but it should probably be lowered about 100mm as there's room for this.)

If the weight tensioner fails to operate as intended, the OHW system can start to behave as a fixed-anchored OHW System which it was not designed as, and the consequences can be dire in many regards. This includes over-tensioning conductors to breaking point (especially any instances of worn contact wire in the run), reduced clearances above catenary to bridges, etc., or clearances below contact to top of train, altered turnout wiring geometry, increased blowout affecting pantograph security, etc.

A "Users Manual" is available that explains the operation of the WeightSet program.

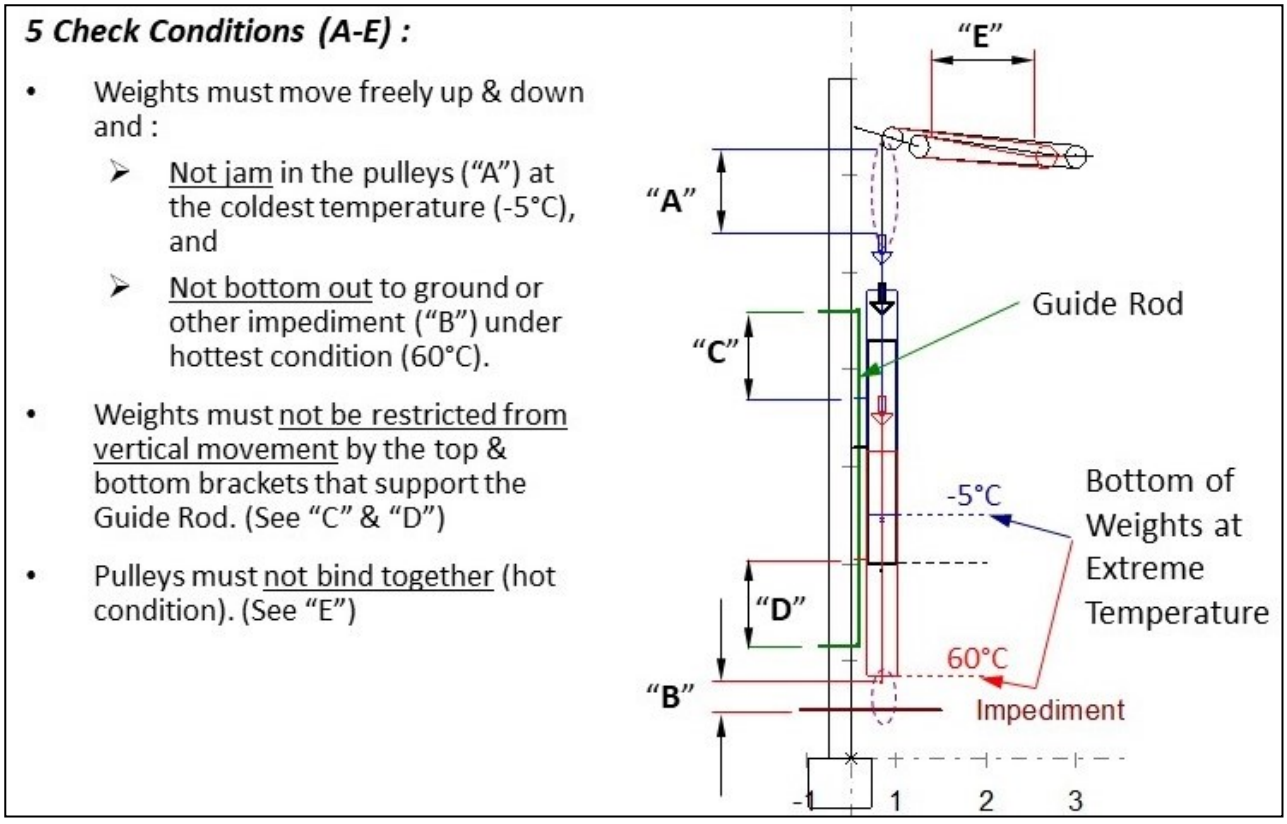

5 Check Conditions (A-E) :
Weights must move freely up & down and :
Not jam in the pulleys ("A") at the coldest temperature (-5°C), and
Not bottom out to ground or other impediment ("B") under hottest condition (60°C).
Weights must not be restricted from vertical movement by the top & bottom brackets that support the Guide Rod. (See "C" & "D")
Pulleys must not bind together (hot condition). (See "E")
"E"
"A"
"C"
Guide Rod
-5°C
Bottom of Weights at Extreme Temperature
"D"
60°C
"B"
Impediment
-1
1
2
3

Figure 346 - The 5 critical clearances for Weight Tension Regulators

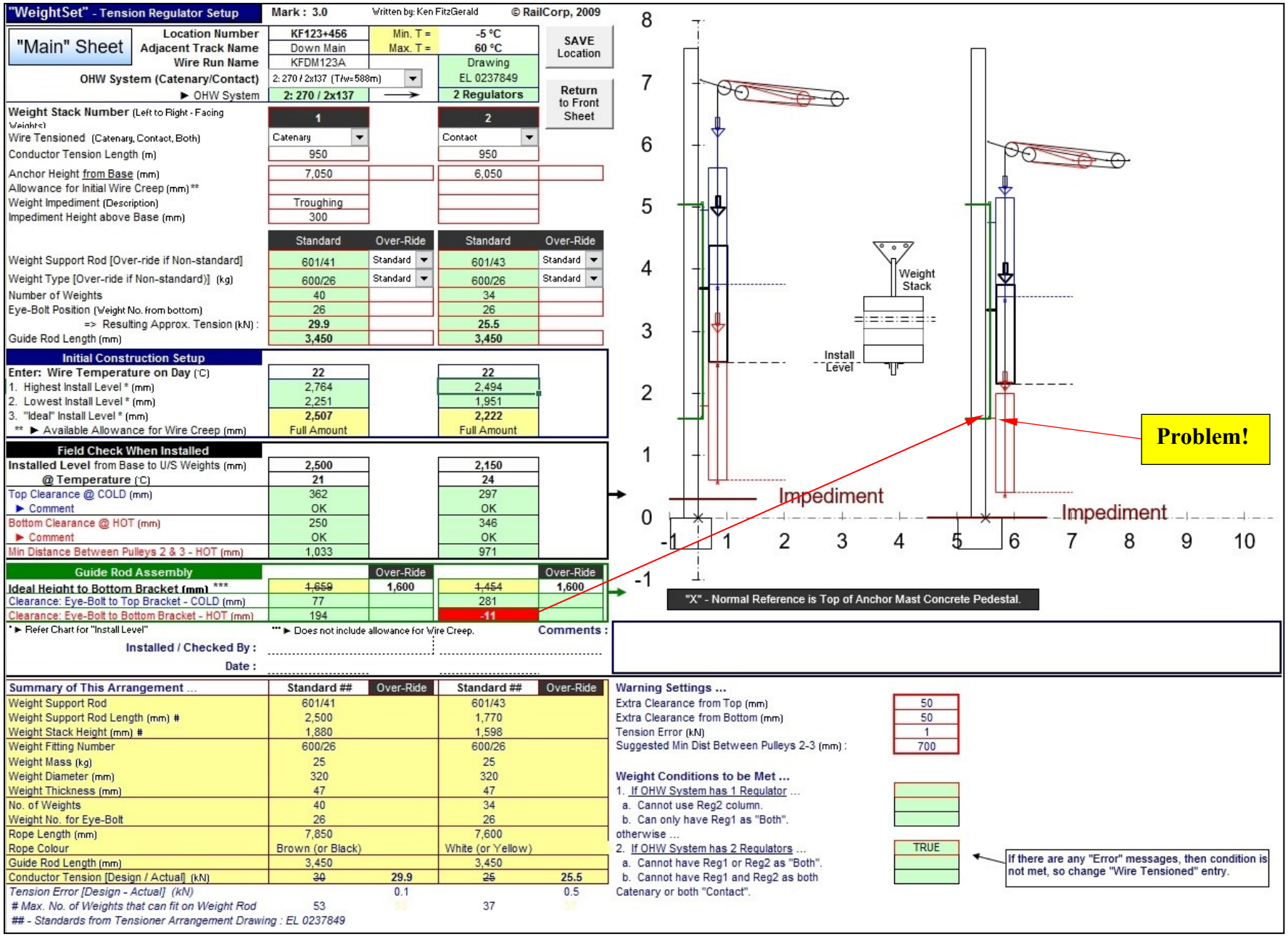
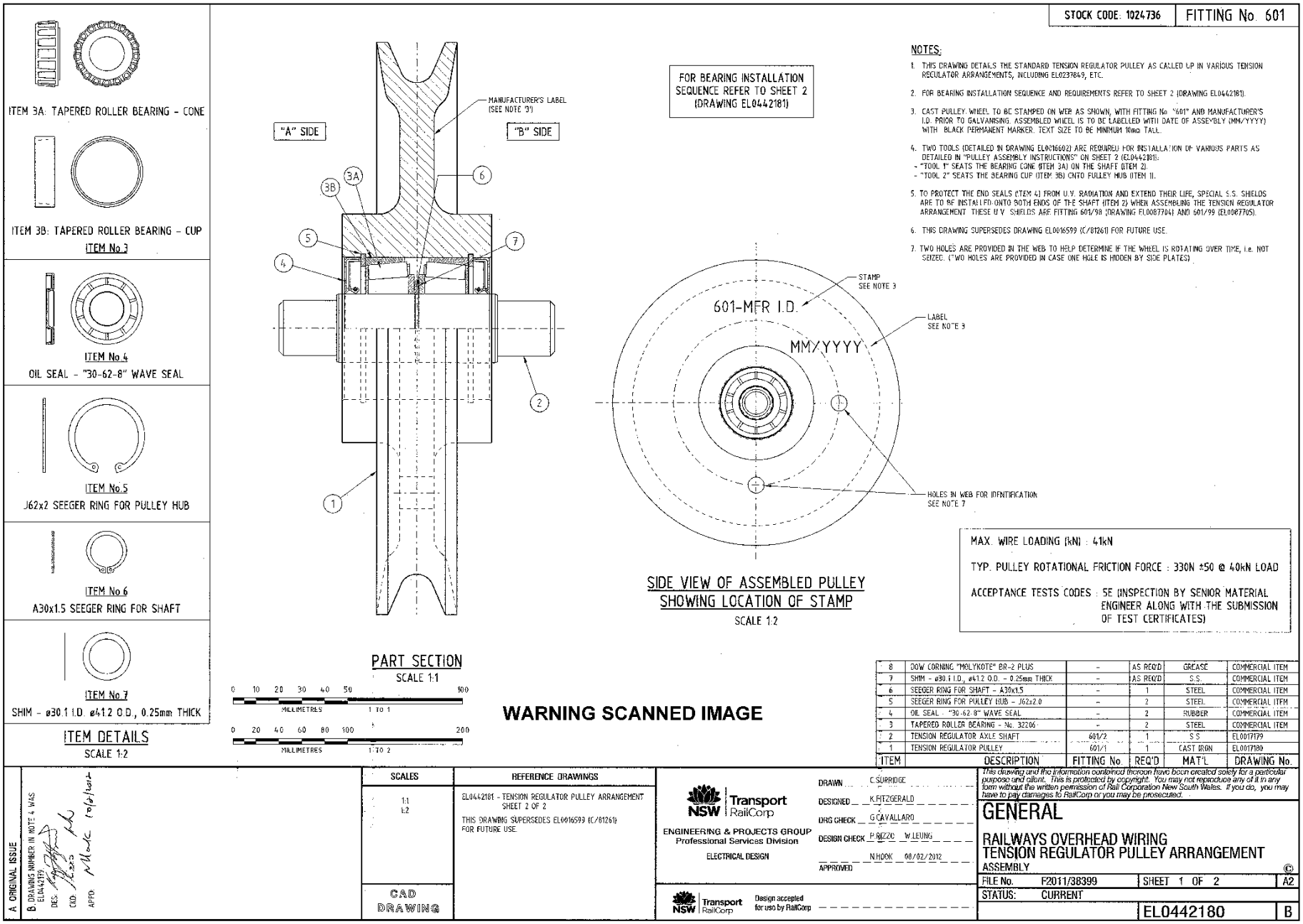


Figure 347 - Example of "WeightSet" Output


STOCK CODE: 1024736
FITTING No. 601
ITEM 3A: TAPERED ROLLER BEARING - CONE
ITEM 3B: TAPERED ROLLER BEARING - CUP
ITEM No.3
ITEM No.4
OIL SEAL - "30-62-8" WAVE SEAL
ITEM No.5
J62x2 SEEGER RING FOR PULLEY HUB
ITEM No.6
A30x1.5 SEEGER RING FOR SHAFT
ITEM No.7
SHIM - ø30.1 I.D. ø41.2 O.D., 0.25mm THICK
ITEM DETAILS
SCALE 1:2
"A" SIDE
"B" SIDE
MANUFACTURER'S LABEL (SEE NOTE 3)
FOR BEARING INSTALLATION SEQUENCE REFER TO SHEET 2 (DRAWING EL0442181)
NOTES:
1. THIS DRAWING DETAILS THE STANDARD TENSION REGULATOR PULLEY AS CALLED UP IN VARIOUS TENSION REGULATOR ARRANGEMENTS, INCLUDING EL0239849, ETC.
2. FOR BEARING INSTALLATION SEQUENCE AND REQUIREMENTS REFER TO SHEET 2 (DRAWING EL0442181).
3. CAST PULLEY WHEEL TO BE STAMPED ON WEB AS SHOWN, WITH FITTING No "601" AND MANUFACTURER'S I.D. PRIOR TO GALVANISING. ASSEMBLED WHEEL IS TO BE LABELLED WITH DATE OF ASSEMBLY (MM/YYYY) WITH BLACK PERMANENT MARKER. TEXT SIZE TO BE MINIMUM 10mm TALL.
4. TWO TOOLS (DETAILED IN DRAWING EL0016602) ARE REQUIRED FOR INSTALLATION OF VARIOUS PARTS AS DETAILED IN "PULLEY ASSEMBLY INSTRUCTIONS" ON SHEET 2 (EL0442181).
- "TOOL 1" SEATS THE BEARING CONE (ITEM 3A) ON THE SHAFT (ITEM 2).
- "TOOL 2" SEATS THE BEARING CUP (ITEM 3B) ONTO PULLEY HUB (ITEM 1).
5. TO PROTECT THE END SEALS (ITEM 4) FROM U.V. RADIATION AND EXTEND THEIR LIFE, SPECIAL S.S. SHIELDS ARE TO BE INSTALLED ONTO BOTH ENDS OF THE SHAFT (ITEM 2) WHEN ASSEMBLING THE TENSION REGULATOR ARRANGEMENT. THESE U.V. SHIELDS ARE FITTING 601/98 (DRAWING EL0087704) AND 601/99 (EL0087705).
6. THIS DRAWING SUPERSEDES DRAWING EL0016599 (C/81261) FOR FUTURE USE.
7. TWO HOLES ARE PROVIDED IN THE WEB TO HELP DETERMINE IF THE WHEEL IS ROTATING OVER TIME, i.e. NOT SEIZED. (TWO HOLES ARE PROVIDED IN CASE ONE HOLE IS HIDDEN BY SIDE PLATES).
STAMP SEE NOTE 3
601-MFR I.D.
MM/YYYY
LABEL SEE NOTE 3
HOLES IN WEB FOR IDENTIFICATION SEE NOTE 7
SIDE VIEW OF ASSEMBLED PULLEY SHOWING LOCATION OF STAMP
SCALE 1:2
MAX. WIRE LOADING (kN) : 41kN
TYP. PULLEY ROTATIONAL FRICTION FORCE : 330N ±50 @ 40kN LOAD
ACCEPTANCE TESTS CODES : 5E (INSPECTION BY SENIOR MATERIAL ENGINEER ALONG WITH THE SUBMISSION OF TEST CERTIFICATES)
PART SECTION
SCALE 1:1
0 10 20 30 40 50 100
MILLIMETRES 1 TO 1
0 20 40 60 80 100 200
MILLIMETRES 1 TO 2
WARNING SCANNED IMAGE
8 DOW CORNING "MOLYKOTE" BR-2 PLUS - AS REQ'D GREASE COMMERCIAL ITEM
7 SHIM - ø30.1 I.D., ø41.2 O.D. - 0.25mm THICK - AS REQ'D S.S. COMMERCIAL ITEM
6 SEEGER RING FOR SHAFT - A30x1.5 - 1 STEEL COMMERCIAL ITEM
5 SEEGER RING FOR PULLEY HUB - J62x2.0 - 2 STEEL COMMERCIAL ITEM
4 OIL SEAL - "30-62-8" WAVE SEAL - 2 RUBBER COMMERCIAL ITEM
3 TAPERED ROLLER BEARING - No. 32206 - 2 STEEL COMMERCIAL ITEM
2 TENSION REGULATOR AXLE SHAFT 601/2 1 S.S. EL0017179
1 TENSION REGULATOR PULLEY 601/1 1 CAST IRON EL0017189
ITEM DESCRIPTION FITTING No. REQ'D MAT'L DRAWING No.
A ORIGINAL ISSUE
B DRAWING NUMBER IN NOTE 4 WAS EL0442179
DES. CKD. APPD.
SCALES 1:1 1:2
CAD DRAWING
REFERENCE DRAWINGS
EL0442181 - TENSION REGULATOR PULLEY ARRANGEMENT SHEET 2 OF 2
THIS DRAWING SUPERSEDES EL0016599 (C/81261) FOR FUTURE USE.
NSW Transport RailCorp
ENGINEERING & PROJECTS GROUP
Professional Services Division
ELECTRICAL DESIGN
DRAWN C.SURRIDGE
DESIGNED K.FITZGERALD
DRG CHECK G.CAVALLARO
DESIGN CHECK P.RIZZO W.LEUNG
APPROVED N.HOOK 08/02/2012
Design accepted for use by RailCorp
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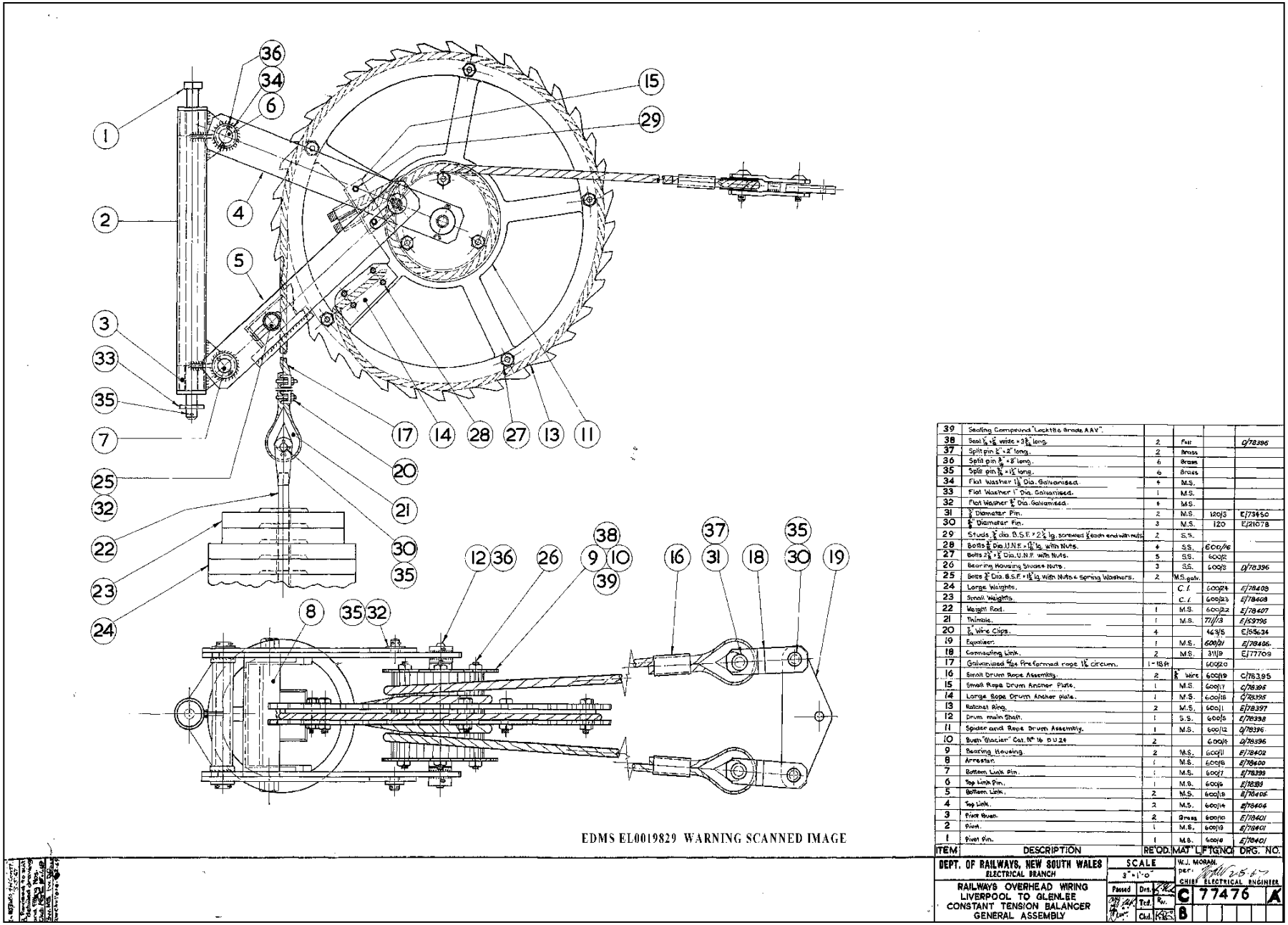
GENERAL
RAILWAYS OVERHEAD WIRING
TENSION REGULATOR PULLEY ARRANGEMENT
ASSEMBLY
©
FILE No. F2011/38399
SHEET 1 OF 2
A2
STATUS: CURRENT
EL0442180
B

Figure 348 - Part of standard Tension Regulator Pulley Assembly drawing EL0442180



ITEM	DESCRIPTION	RE'QD.	MAT'L	FTG NO.	DRG. NO.
39	Sealing Compound "Loctite Grade AAV".				
38	Seal $\frac{1}{8}$"×$\frac{1}{8}$" wide×3$\frac{1}{8}$" long.	2	Felt		Q/78396
37	Split pin $\frac{1}{8}$"×2" long.	2	Brass		
36	Split pin $\frac{1}{8}$"×8" long.	6	Brass		
35	Split pin $\frac{1}{8}$"×1$\frac{1}{2}$" long.	6	Brass		
34	Flat Washer 1$\frac{1}{8}$" Dia. Galvanised.	4	M.S.		
33	Flat Washer 1" Dia. Galvanised.	1	M.S.		
32	Flat Washer $\frac{1}{2}$" Dia. Galvanised.	4	M.S.		
31	$\frac{3}{4}$" Diameter Pin.	2	M.S.	120/3	E/73450
30	$\frac{5}{8}$" Diameter Pin.	3	M.S.	120	E/21078
29	Studs $\frac{3}{4}$" dia. B.S.F.×2$\frac{1}{2}$" lg. screwed $\frac{1}{2}$" each end with nuts.	2	S.S.		
28	Bolts $\frac{5}{8}$" Dia. U.N.F.×1$\frac{1}{2}$" lg. With Nuts.	4	S.S.	600/16	
27	Bolts 2$\frac{1}{2}$"×$\frac{1}{2}$" Dia. U.N.F. with Nuts.	5	S.S.	600/2	
26	Bearing Housing Studs & nuts.	3	S.S.	600/3	Q/78396
25	Bolts $\frac{3}{4}$" Dia. B.S.F.×1$\frac{1}{2}$" lg. With Nuts & Spring Washers.	2	M.S. galv.		
24	Large Weights.		C.I.	600/24	E/78408
23	Small Weights.		C.I.	600/23	E/78408
22	Weight Rod.	1	M.S.	600/22	E/78407
21	Thimble.	1	M.S.	71/13	E/59706
20	$\frac{3}{4}$" Wire Clips.	4		463/5	E/58634
19	Equaliser.	1	M.S.	600/21	E/78406.
18	Connecting Link.	2	M.S.	311/9	E/77709
17	Galvanised $\frac{9}{16}$" Preformed rope 1$\frac{1}{8}$" circum.	1-18ft		600/20	
16	Small Drum Rope Assembly.	2	$\frac{1}{2}$" Wire	600/19	C/78395
15	Small Rope Drum Anchor Plate.	1	M.S.	600/17	Q/78395
14	Large Rope Drum Anchor plate.	1	M.S.	600/18	Q/78395
13	Ratchet Ring.	2	M.S.	600/1	E/78397
12	Drum main Shaft.	1	S.S.	600/5	E/78398
11	Spacer and Rope Drum Assembly.	1	M.S.	600/12	Q/78396.
10	Bush "Glacier" Cat. No. 16 D.U.24	2		600/9	Q/78396
9	Bearing Housing.	2	M.S.	600/11	E/78402
8	Arrester.	1	M.S.	600/15	E/78400
7	Bottom Link Pin.	1	M.S.	600/7	E/78399
6	Top Link Pin.	1	M.S.	600/6	E/78399
5	Bottom Link.	2	M.S.	600/10	E/78405
4	Top Link.	2	M.S.	600/14	E/78404
3	Pivot Bush.	2	Brass	600/20	E/78401
2	Pivot.	1	M.S.	600/13	E/78401
1	Pivot Pin.	1	M.S.	600/8	E/78401

Figure 349 - Drawing of Liverpool to Glenlee Tension Regulator arrangement

LIVERPOOL TO GLENLEE TENSION REGULATOR

I understand that one of the first tension regulator arrangements used in Sydney was the Liverpool to Glenlee arrangement (way back in 1968), as shown in *Figure 349* and also in *Figure 350*.

In this arrangement, the weight stack is connected using wire rope wound around a large diameter wheel, and the OHW conductors are tensioned using wire rope wound around a smaller diameter wheel on a shaft in common with the larger wheel. The ratio of large wheel to small wheel gives a 3:1 mechanical advantage, achieving the same outcome as the more modern 3-pulley arrangement, but using less space.

The weights are trapped within the confines of the anchor structure, which unfortunately made inspections rather awkward.

Two such tensioning arrangements were required for this special single catenary / twin contact OHW system. One tensioned the catenary and the next tensioned the twin contacts.

This arrangement also incorporated a special ratchet mechanism as part of the large wheel. This ratchet was intended to act as a brake if the OHW conductors ever broke, to prevent the weights from plummeting all the way to ground and causing damage.

However, I've been told that it rarely worked as intended, and the weights still fell to ground. Maybe there was simply too much inertia in the weights when they fell, or it took too long for the braking mechanism to come into play to do any good in this highly loaded situation (?). No one seems to really know, and it is likely a rare event in any case.

Figure 350 - Liverpool-Glenlee Tension Regulators

DAMAGE DUE TO OHW CONDUCTOR BREAKAGE

Figure 351 gives an idea of the sort of damage that can happen if the weight stack should suddenly plummet to ground. This can happen, for instance, if the tensioned wire (catenary or contact) snaps nearby, or if a tension regulator fitting fails. In this case, the concrete portal footing pedestal was slightly damaged.

Figure 351 - Damage when Weight Stack plummets

However, if the wire snaps a few hundred metres away from the weights, then each successive cantilever can swing, and in doing so can lower the weights down but not have them crash to ground.

I was able to witness this type of incident at Chatswood RES late on a Sunday night while finalising the adjustments to a newly installed (but temporary staging) OHW run. In this situation, a catenary termination wrapon failed at the remote anchor location, but successive cantilevers in the run simply swung to take the catenary tension.

See *Figure 352* which is a photo of the affected set of weights after the incident – the catenary weights lowered by about 500mm but did not touch the ground. (Thankfully the very limited damage meant the OHW went back into service for the Monday morning service without any delay.)

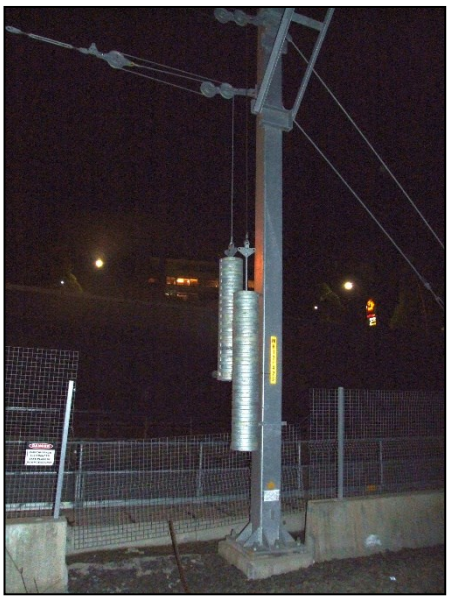


Figure 352 - Failed Catenary causes Weights to lower

So it seems that, provided the catenary wire or other termination fittings don't fail close to or at the tension regulator location, there is a good chance that the successive support cantilevers (including pull-off arms) can each help share the remaining weight-generated tension load in catenary or contact wires.

WEIGHT CAGES

Sometimes weight tensioners are installed in situations that may pose an increased risk of adverse outcome if the weight stack suddenly drops to the ground and the individual weights scatter. The scattered weights themselves are more likely to pose the problem.

In such situations, special "*weight cages*" can be installed to help control the risk.

One particular example is at the Central Flyovers, where the weights are installed almost directly above a track below. See *Figure 353*. If the weights fall but remain as a stack, there is unlikely to be a problem. However, if they individually scatter, they could fall onto a passing train below or cause some other problem.

So, the cage was designed and installed to constrain the many individual weights (in this case 49 × 25kg weights). The stack of weights can be fully accessed for subsequent maintenance by 2 hinged doors that are normally locked closed with 4 evenly distributed bolts.

At the base below the weights is a low steel platform with a thick rubber surface that's intended to help absorb some of the impact load in case the weight stack falls.

Figure 353 - Installation of Weight Cage at Central Flyovers

3.4.2.5 Design Notes

Tension regulators are extremely important pieces of equipment to a regulated OHW system, as they are meant to apply the correct design tension to benefit the entire tension length of the wire run, irrespective of conductor temperature. In particular, the pulleys play an important role in the success (or otherwise) of a regulated OHW system, so I've included more information about the inner workings of these pulleys.

Refer to *Section 3.4.0.5* for more information and diagrams relating to some of the below aspects.

FRICTION

Friction in bearings causes a deviation from the design tension, which can adversely impact the geometry and performance of the affected wire run. The friction in the assembly (with 3 pulleys) is normally accepted as causing a tension deviation of about 3%. Refer to arrangement drawing EL0442180 which shows "Typical Pulley Rotational Friction Force: 330N @ 40kN Load" – this equates to approx. 3% for the combined 3 pulleys.

Too much friction, caused by the bearings corroding inside or wearing out, can lead to them totally seizing. In this case, the deviation from design tension (causing both higher and lower tension) can be so great as to cause the pulley axle/s to rotate in the bearing holes in both side

plates. This is not a good outcome as it can no longer can be considered a proper tension regulator for delivering the correct tension – instead behaving more like a fixed-anchored system that it wasn't designed to be – horror!

The pulleys should be checked periodically to ensure free rotation. Ideally there should be some permanent marking on both ends of the axle to check that the shaft itself isn't rotating over time. At some stage a pair of holes at right angles were introduced in the design of the pulleys in an attempt to check for relative pulley movement (i.e. not seized). See *Figure 342*.

Even if the roller bearings don't totally seize, excessive friction means that the weights stay put (i.e. remain "stuck") until there's sufficient *change of tension* in the OHW conductors to overcome the friction, before movement finally occurs. This is "*stiction*", which is the term used to describe the friction which tends to prevent stationary surfaces from being set in motion.

When friction is finally overcome, the pulley wheels turn and the weight stack moves to a new equilibrium position and the process begins again. Unfortunately, during the time the weights are temporarily "stuck", the corresponding tension length of wire is affected, and its tension can either slightly increase or decrease (depending on the direction of temperature change) with corresponding effects in each affected bay.

Sometimes the weights can be nudged and they move to a completely different vertical position, as a result of overcoming this stiction.

This non-ideal reaction to friction is the main reason why the weights really can't be used as "temperature gauges", even though this approach (with temperature graduation template) had been tried in certain districts over the past decade or more. I'd be surprised if complaints weren't received from the travelling public advising that the temperature gauges aren't working and should be fixed! It might work for a single wheel, but 3 wheels offers too much friction in this case. (Apart from that, the temperature actually measured in this situation is average wire temperature, not ambient temperature.) But I digress!

GREASE

As mentioned previously, the inside of the pulley hub is packed with grease to reduce friction and wear, and to help keep moisture away from the roller bearings.

The character of these pulley wheels is that they need to handle extremely heavy loads, and they rotate very slowly (maybe a few rotations each way every day, depending on temperature extremes).

Unfortunately, the rollers can tend to squeeze out the grease over time. Also, the grease can tend to harden over the years, and congeal away from where it's needed at the bearing surfaces.

Aside:

> There had been recent talk of the possibility of modifying the design slightly to bathe the bearings in oil (to about axle level) instead of using grease. The seals are already there to prevent oil leakage, and maybe a threaded plug or grease nipple could be used to fill and seal the oil inside during manufacture.
>
> If this was done, then any oil leaks would be observed from the ground, and this should prompt for the pulley wheel to be replaced (which is a far more controlled approach than is currently the case with the condition of the grease hidden from view).

The big benefit is that the oil remains liquid and so can more effectively penetrate the bearings (on a daily basis).

Probably the only thing that needs checking out is whether the seals would pop due to internal air pressure after going from cold to hot each day (especially summer conditions). However, with so much air space inside, this is unlikely to be a problem.

This is one area that could benefit from an expert review on the matter, and with any recommended improvements implemented. This is because the pulleys are such a vital part needed for the proper functioning of the OHW infrastructure these days.

EQUALIZER BAR & PROBLEMS

Equalizer bars provide a simple, accurate and effective way to deliver the design tension to 2 wires from a common tension source (weight tensioner these days). Even so, there are a few traps for the unwary, as described below.

Triangular Equalizer Bars

Some early equalizer bars (the ones shaped in a shallow triangle, e.g. initial fitting 601/12) have been banned from use for tensioning both the catenary and contact wires from a single weight stack, because they do not always provide the required tensions. Refer to a) in *Figure 354*. Also see *Figure 362* a few pages further on for an instance of this obsolete fitting in the field.

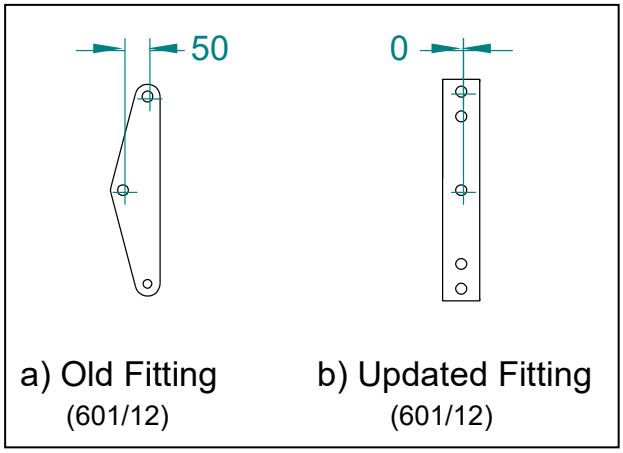


Figure 354 - Old (left) and updated (right) Equalizer Bars

For whatever reason, the contact wire, in particular, can tend to "creep" (permanently lengthen) over time, much more so than the catenary wire does.

This wire stretch can cause the equalizer bar to rotate from being vertical. Indeed, any misalignment from this fitting's normal vertical orientation (i.e. any rotation) can help give tell-tale signs of creep or some other problem with that specific run of OHW.

Figure 354 also shows the updated replacement fitting b), but unfortunately both share the same fitting number.

The 50mm offset shown in case a) can cause a tension problem, as discussed below.

Surprisingly, the solid contact wire tends to continue to stretch over the years, even though the majority of the initial stretch is taken out in the first few hours after being super-tensioned and then correctly tensioned when newly installed. However, there is much less tendency for the multi-stranded catenary wire to stretch over time.

Any relative change in conductor length – contact versus catenary – can be taken up when using an equalizer bar. But it causes the bar to rotate slightly (and progressively more over time as more relative stretch happens).

Figure 355 shows how much the catenary and contact wire tensions can differ relative to each other and relative to their design tension (of 16.5kN tension each wire in this example), due to the contact wire stretching over time and rotating the older triangular equalizer bar. The *geometry* of the bar plays an important part in the problem.

As the device rotates, the contact tension reduces and the catenary tension increases, as given in the diagram.

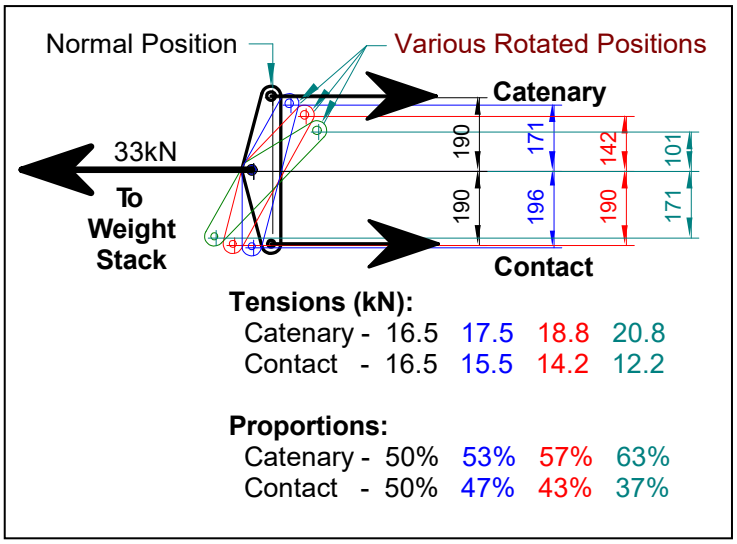


Figure 355 - Tension deviation due to Contact stretch with old Equalizer Bar

It is obvious that the performance of the OHW system will suffer significantly due to these sorts of *tension changes* away from the design tension.

For the entire OHW run, there might be problems resulting from the lowered contact tension – with slightly lowered contact wire heights, but more importantly excessive contact wire blowout at mid-bays, pantograph dynamic performance issues, alignment issues with other wires at turnouts, etc. Increased catenary tension can also causes other problems, such as less vertical clearances to overline bridges, contact hogging in the tension length, etc.

Overall, it's not a good situation, which is the reason why the shape was abandoned in 1982.

The updated shape b) in *Figure 354* does not cause this same problem. As the bar rotates, the vertical offsets that determine the proportions of delivered tension remain the same as each other, and so the tensions remain in the same proportions (50/50). This is unless the bar can no longer rotate – see next heading.

However, even though the edict was issued to have the old style replaced over time, every now and then they seem to turn up in the field when walking the track.

Note:

A standard triangular link (fitting 601/63) is used as a type of "equalizer bar" in tensioning the twin contacts (*Figure 356*). In this configuration it is OK to use. This is because any slight rotation of the fitting, causing slight imbalance of tension loads delivered to each contact wire, should make virtually no difference to their overall performance. (E.g. the additional sag between droppers of one contact wire compared to the adjacent contact wire will likely be indiscernible.)

And in any case, both contact wires should stretch by a similar amount over time. That is, except if the rotation is as a result of some contact splice or other contact connection moving slightly relative to the adjacent contact wire. In which case, this situation should be checked out for its cause if identified in the field.

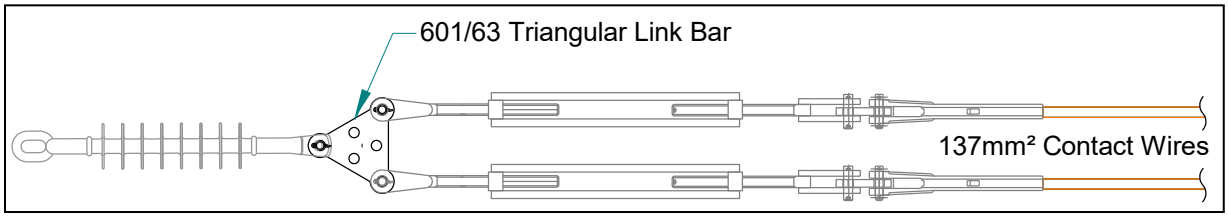


Figure 356 - Standard Triangular Link as Equalizer Bar (plan view)

Equalizer Bar Prevents Further Rotation

The equalizer bar resides in a clevis arrangement of 2 side plates with a welded spacer to keep the plates spaced apart. Refer to *Figure 357*.

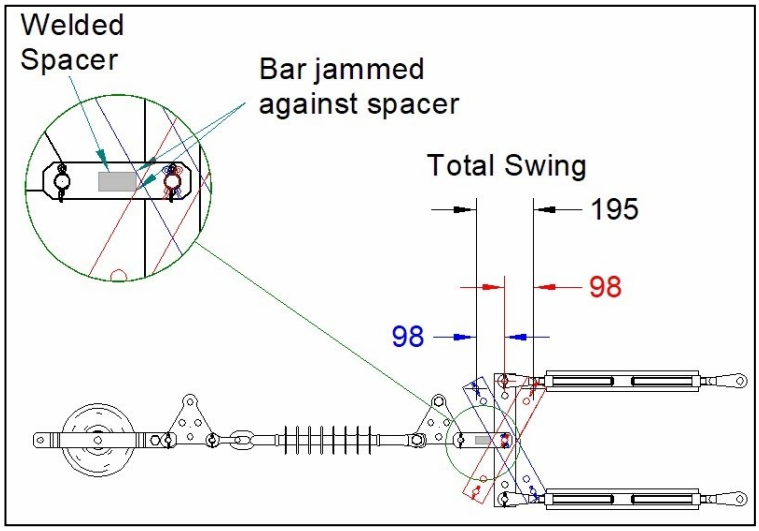


Figure 357 - Total swing of Equalizer Bar before being jammed

A stainless steel pin allows the equalizer bar to have free rotation as needed when the tensioned wires move relative to each other over time, most notably due to wire stretch (this mostly happens to the contact wire for whatever reason).

However, rotation of the bar stops if and when it jams against the welded spacer piece. The rotation limits are shown in *Figure 357*. When this happens, the delivered tensions will no longer be in their correct proportions. An actual example of this is given in *Figure 359*.

This situation can have the same consequences as detailed in the "Triangular Equalizer Bars" section above. For example, when the contact wire permanently stretches over time, this situation results in more tension being delivered to the catenary wire than to the contact wire. See ***case (b)*** in *Figure 358*. Consider the fairly extreme case where the contact wire stretches by 1 metre or more – the catenary wire ends up taking almost twice its normal tension and the contact wire gets very little, and so it sags excessively between droppers as a result. The functionality of both wires suffers greatly, in different ways.

Often when an equalizer bar's orientation is *corrected*, it will be deliberately set in a position to overcompensate, as shown in ***case (a)*** in *Figure 358*. This then allows for some considerable contact wire stretch in the future without the need to constantly readjust the bar back to vertical.

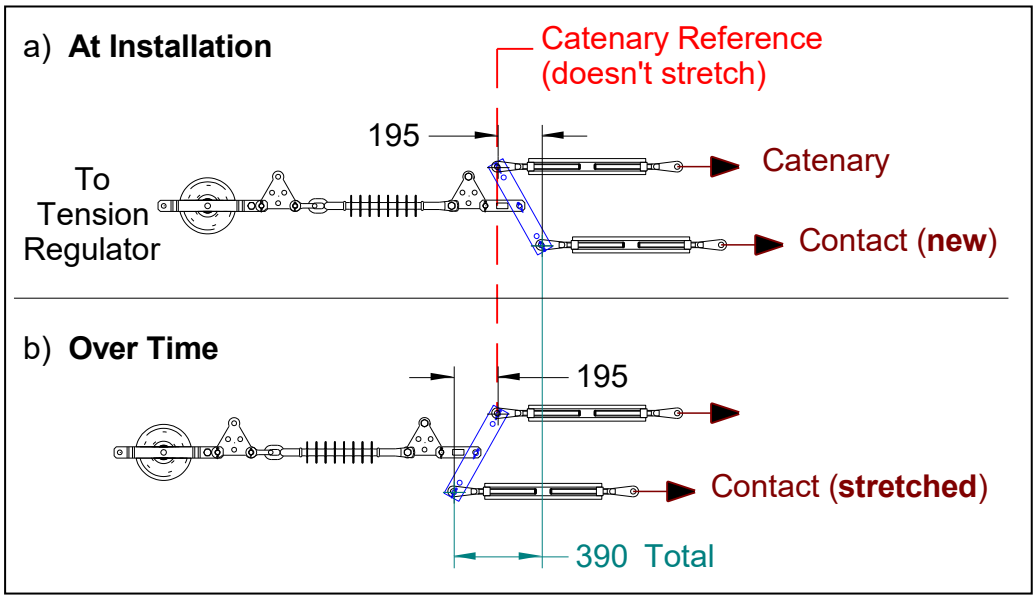


Figure 358 - Contact wire stretch may lead to Equalizer Bar binding

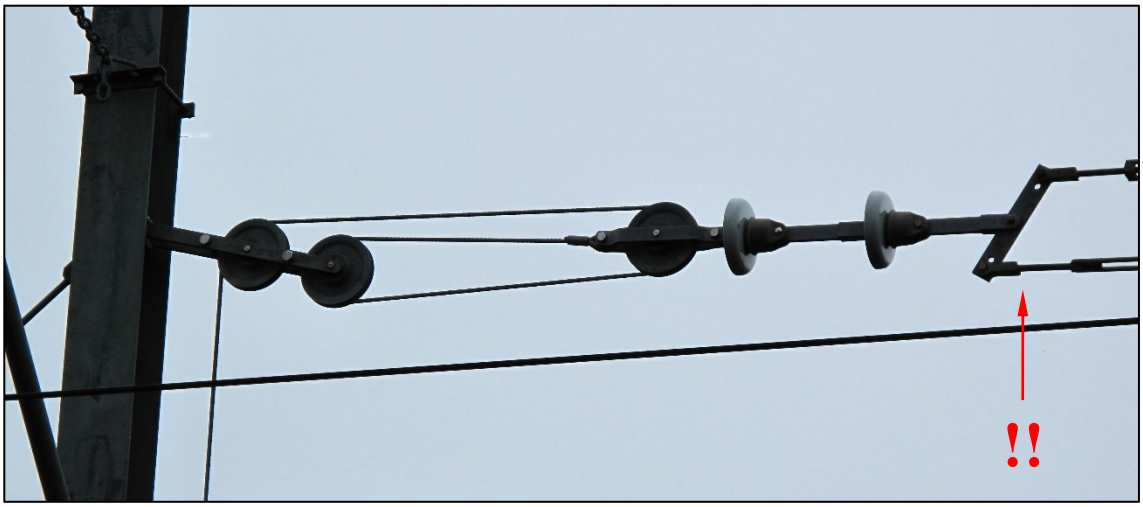


Figure 359 - Equalizer Bar "locked" from further rotation (= ineffective)

Equalizer Bars at Both Ends of Wire Run

If a regulated wire run has a tension regulator at one end and a fixed anchor at the other end, then it cannot use equalizer bars at both ends.

This is because it can allow the catenary and contact wires (that are tensioned through these bars) to drift relative to each other, causing problems with the vertical alignment of droppers and the like. In other words, the wiring position is no longer controlled or constrained, making it a somewhat unstable situation.

The problem is that equalizer bars at both remote ends of the wire run can freely rotate (although rotation would both be in the same direction). But even though the delivered tension can be accurate, this means the entire catenary wire run can drift towards Sydney and the contact wire run (in sympathy) can drift towards the country, and vice-versa. So, at any particular point in the run, the vertical misalignment between catenary and contact is twice the amount of drift. Indeed, it can be that the catenary drifts to Sydney one day and the next day it drifts to country!

Droppers that loop over the catenary saddle clamp under bridges (where the system depth is low) are particularly vulnerable, as the dropper loop can dislodge from its catenary saddle clamp and rest on the catenary wire itself, which can then become damaged with wear or arcing over time.

This exact situation happened at Wyee soon after electrification of the Gosford to Newcastle line in the early 1980's. The correction was simple, and the lesson was learnt.

To correct the problem, one end of the wire run needs to be directly fixed to anchor, and this is normally done at the "F"ixed end. After all, the equalizer bar was developed for tension regulators to deliver proportional tensions to both catenary and contact wires.

Multiple Holes

A straight equalizer bar is designed to have pairs of holes at both top and bottom (giving 5 holes total). This type of bar is shown in *Figure 358* and *Figure 359*.

With this situation, the extreme top and bottom holes should be used to connect the conductors, as this will allow the contact wire to stretch the most before the bar rotation eventually becomes jammed and needs to be corrected back.

I understand the other 2 holes are there for temporary rigging purposes (to remove an insulator, etc.).

IMPROVED GUIDE ROD SUPPORT BRACKETS

In 2007 a totally new configuration of the "guide rod support bracket" was developed and signed off to replace the original arrangement. Both arrangements are shown in *Figure 360*.

The new arrangement was needed because the proper vertical alignment of the guide rod could not always be achieved with the old arrangement (this was evident in many situations around the network). The eye-bolt in the weight stack was often seen bearing heavily on the guide rod (and often significantly bowing this rod). And sometimes the guide rod alignment was nowhere near where it was meant to be for proper alignment with this eye-bolt (in some cases causing the rod to be abandoned totally!).

This adjustment limitation was because the it came via 2 threaded rods with lock nuts on each bracket, giving adjustment in one direction only (although sometimes the attachment bracket could be flipped to provided limited adjustment in another direction).

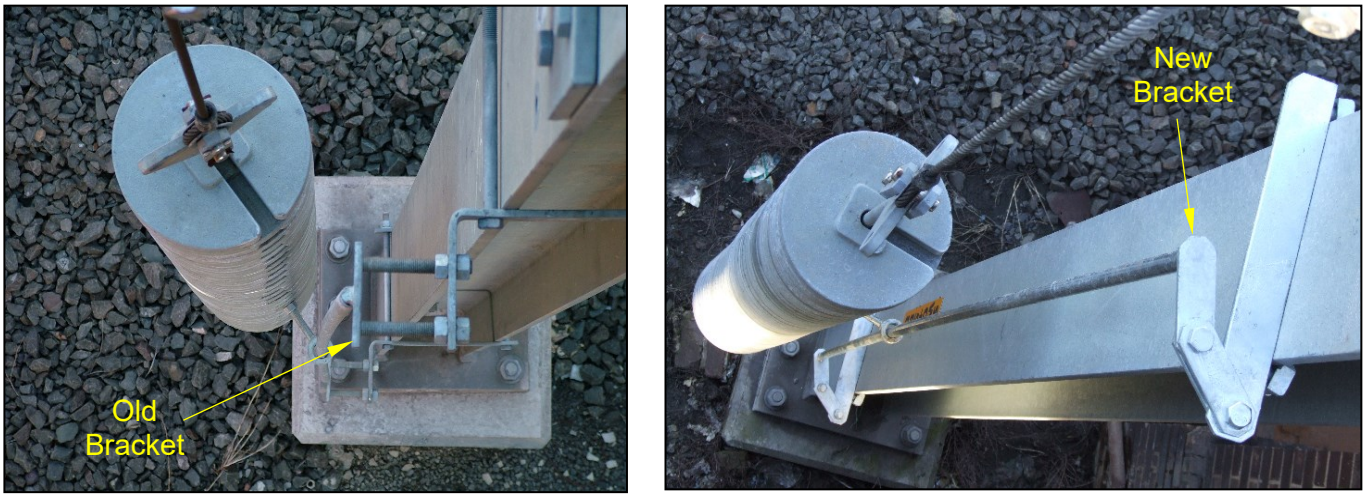


Figure 360 - Top view comparison of old (left) & new (right) Guide Rod Support Brackets

The new arrangement has fitting numbers 601/72 to 75 (4 arrangements for 4 different size OHW support structures).

It provides superior adjustability compared to its predecessor. It achieves this by having 2 sets of plates (with 100mm hole centres), that can rotate independently in series to the desired position – like the movement of your arm. But it requires the 2 pivoting bolts to be tightly locked off to prevent the arm from moving out of alignment if the rod is abruptly loaded.

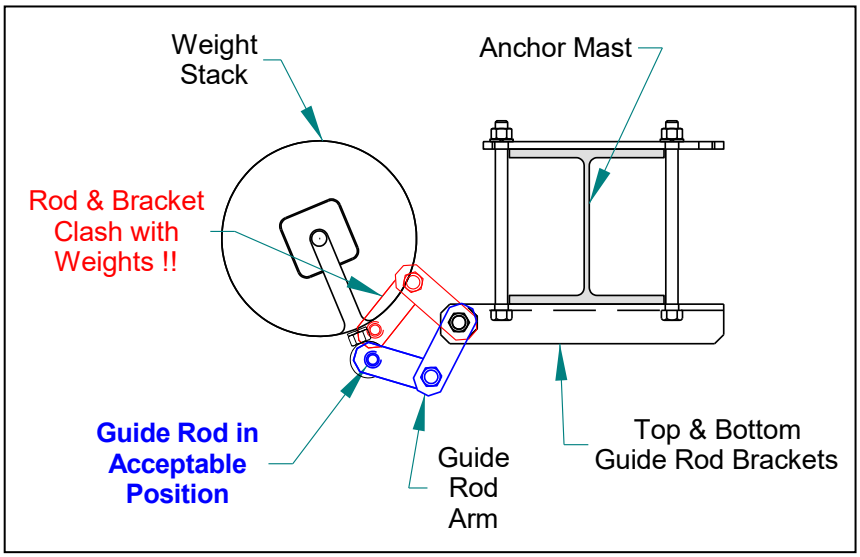


Figure 361 - Correct orientation of Guide Rod Bracket Arm

The weight stack also needs to be checked for suitable clearance to the brackets when in their final position. This may require the elbow in the arm to be reconfigured to come from the opposite direction as shown in *Figure 361*.

GALVANISED WEIGHTS

Someone once told me that the galvanising on cast iron weights was a waste of tax-payers' money, because once the surface rust occurs on the weights, they don't seem to corrode much from then on (I guess because of the nature of cast iron). Refer to the weights of the two anchor arrangements in *Figure 362*.

I didn't have an argument against this back then, but I now know that the real benefit of galvanising the weights is so that you can tell at a glance if internal corrosion of the weight support rod is taking place, with obvious brown-red stains against a grey background indicating rusting.

This is important because much of the weight support rod is hidden from view by the weights. If the crucial weld connecting the weight support rod to the flat plate that the weights rest on is rusting, or if the hidden rod itself is rusting, then this jeopardises the integrity of the entire stack, and could become an operational and possible safety risk (e.g. weights plummet to ground and the tension length of OHW fails).

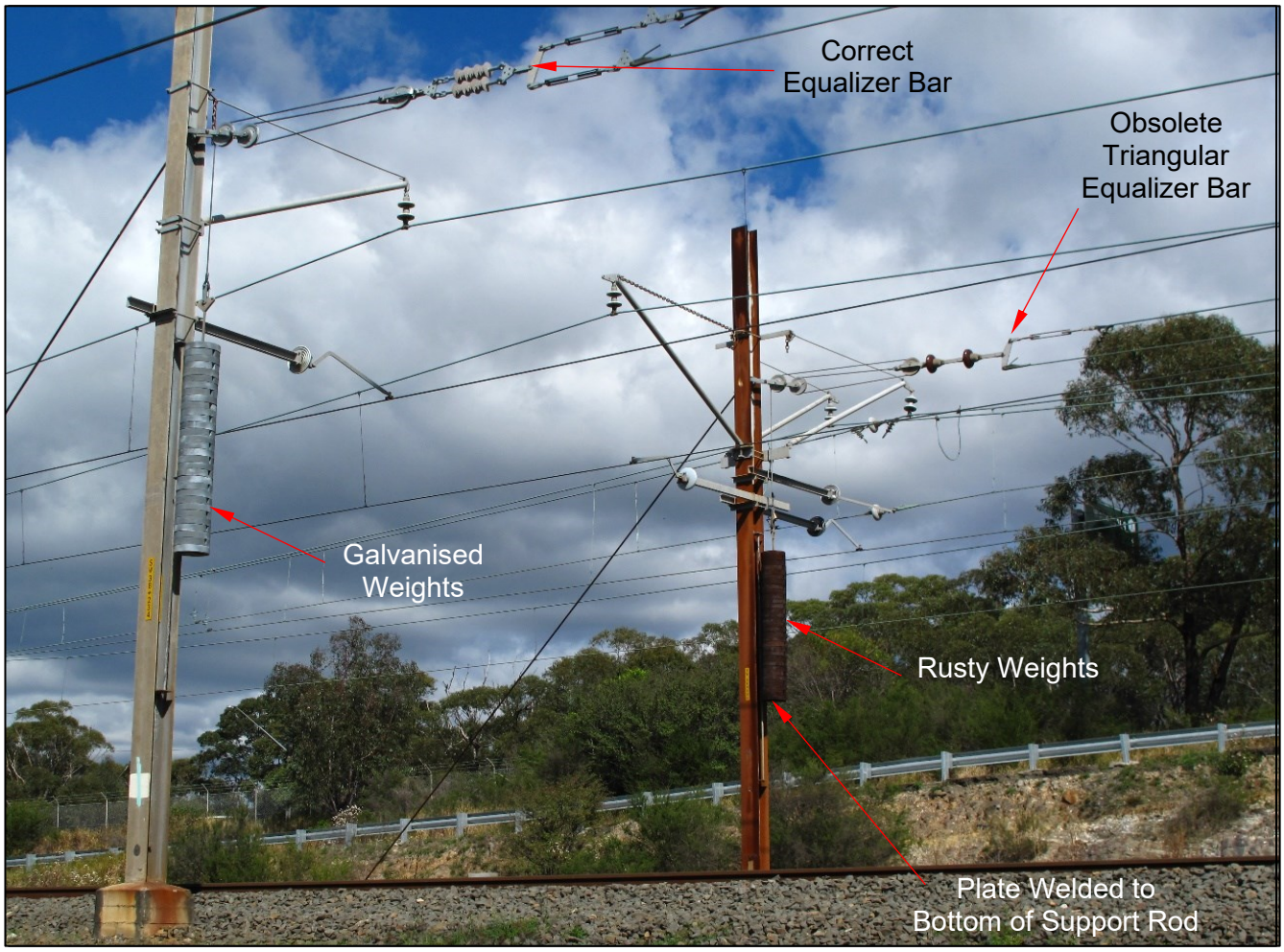


Figure 362 - New & old Tension Regulators

This bottom connection has been recently improved to include 2 welded angles instead of a plate, to allow better internal inspection of this important support point with weights applied.

More than this however, is that rusting is a sign that something is likely not being maintained well, so to the general public there's a bad perception of things not being looked after (when in fact they may be well maintained). *Figure 362* contrasts this situation with galvanised weights on the left-hand and rusty weights on the right-hand anchor arrangement. Which looks better, and is also less obtrusive?

WIRE ROPE

The steel wire rope is extremely strong and needs to be flexible enough to pass around the 250mm diameter tension regulator pulleys (fitting 601/1) without eventual fatigue, even after thousands of cycles.

The wire rope consists of 6 groups of 36 strands arranged (I think) as shown in *Figure 363*.

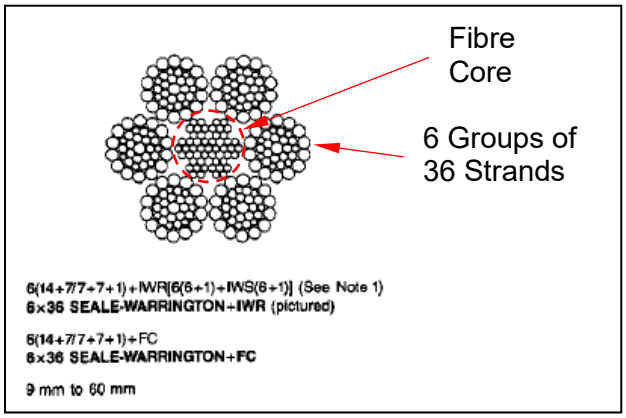


Figure 363 - Wire Rope makeup

The centre of the rope is normally a fibre core that can retain lubricant, which can then help the steel strands glide past each other as the wire rope bends around the pulleys. This in turn minimises wear on the outside of the strands, reduces friction and can help combat any rusting that may start on individual strands.

The original ropes were specified to have each strand galvanised to a certain minimum thickness to prevent rusting. However, in recent times the supplier/s have not provided much coating at all, with the consequence that the ropes often showed signs of rusting from a very early stage after installation (sometimes within 1 or 2 months).

Figure 364 - Corrosion on Wire Rope soon after installation

I understand this problem eventually led to the selection of an alternative wire rope that had strands composed of a metal alloy that does not rust, and this seems to be a good outcome.

Figure 365 gives an idea of the stranding that can ultimately lead to the wire rope snapping. It looks like corrosion was a likely reason for its ultimate demise at Heathcote.

Figure 365 - Failed Wire Rope (Heathcote, 1998)

3.4.2.6 Status (c. 2014)

Weight tensioners are the preferred tensioning arrangement. They are fairly simple devices and have proven to be very reliable when properly maintained.

3.4.2.7 Reference

See *Table 31* for drawing reference.

3.4.3 Gas Tension Regulator

3.4.3.1 Description

A "gas tensioner" appears as a long narrow gas cylinder (with associated linkages) that delivers a reasonable regulated tension within a certain temperature range. They are relatively compact and can be located above the track close to other OHW conductors (with appropriate clearances). Refer to *Figure 366* and *Figure 367*.

Most gas tensioners were installed on the outside viaducts of the Eastern Suburbs Railway, as a means of better controlling the wire under extreme hot and cold temperatures in this external environment – refer to *Section 4.2.3*, *Eastern Suburbs Railway Viaducts* for more details.

As of about 2010, all gas tensioners were removed from the system and replaced with weight tensioners, but I've kept the equipment in this document for future reference.

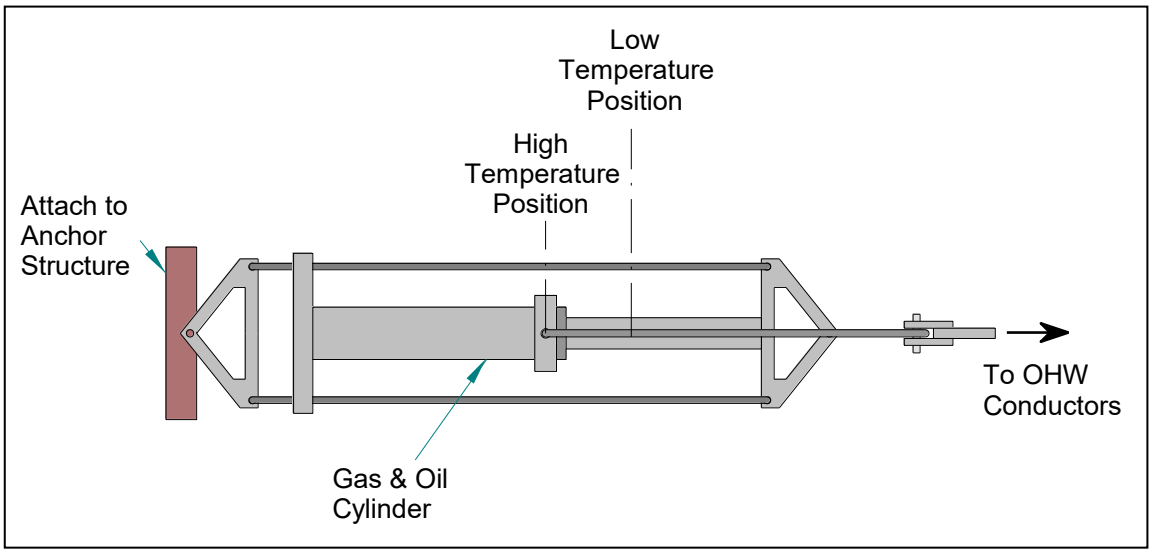


Figure 366 - Gas Tensioner arrangement

3.4.3.2 Function

Gas tensioners rely on the principle that gas expands when hot.

This expanding or contracting gas compensates for the copper conductor lengthening when hot and contracting when cold, thus providing some degree of regulated tension to the catenary and/or the contact wire/s.

An oil reservoir helps to achieve the correct volume of gas needed for the specific tension length of wire.

3.4.3.3 Typical Components

The gas tensioner comes as a completed unit, including gas cylinder, linkages, etc.

Termination insulators and associated hardware are the only extras needed.

3.4.3.4 Configuration

Gas tensioners are partly filled with gas and oil, and they rely on the principle that gas expands when heated.

The tension achieved through these units is generally not as accurate as can be achieved through the weight tensioner.

Gas tensioner units are particularly useful in situations where the installation of weights is virtually impossible, e.g. on viaducts where there is insufficient room or it's impractical to install one or more weight tensioners. In such situations, wherever there's an overlap the tensioners can be installed directly over the track being serviced (however the OHW structure needs to be designed for the resulting enormous anchor loads at this point).

The major drawback with these tensioners is the maintenance requirements of measuring gas pressure, gassing, checking for oil leaks, etc. Because of their relative complexity they are generally not as reliable as the simple weight tensioner, especially in the medium to long term.

From a reliability aspect, at times it was difficult to know if the tensioner was working correctly. If the gas had purged over time, the affected OHW would be tensioned as a fixed-anchored system (which it was not designed to be), and this can lead to several nasty outcomes, e.g. unacceptable blowout with high winds causing pantograph security issues, contact wire sagging onto the roof of a train and stopping services, etc.

The likely tell-tale signs of a malfunctioning gas tensioner are:

- Signs of considerable oil leaks, and
- The gas tensioner in its fully collapsed state (especially if on a warm day).

I understand that, being classified as a *pressure vessel*, means that there are certain protocols required in order to maintain them, including appropriated accredited training.

However, because of ongoing issues with gas tensioners, they have now been removed from the network.

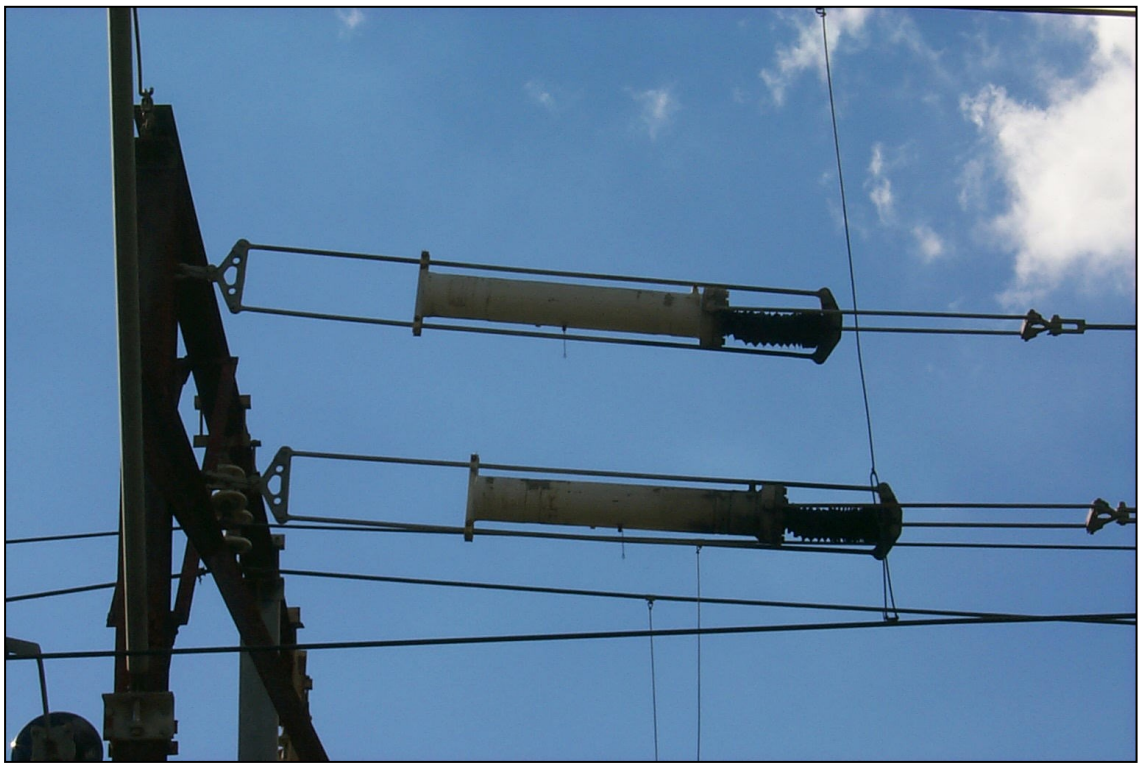


Figure 367 - ESR Gas Tensioner (now removed from service)

3.4.3.5 Design Notes

MECHANISM

According to the NSW Railways "*Overhead Linesman Course – Book 4*", Lecture 36 …

> *"The objective is to maintain a constant pressure of inert gas in the cylinder and so a constant tension in the wire to which it is connected at varying temperatures. This is achieved by movement of the ram to compensate for expansion and contraction of the gas and maintaining tension on the wire in proportion to the pressure".*
>
> *"The cylinder also contains a volume of oil which is changed to vary the volume of gas depending on the length of wire to be tensioned. The shorter the length of wire to be tensioned the smaller the volume of gas required in the cylinder".*

MAINTENANCE

The gas tensioner's classification as a "pressure vessel" has led to a more stringent maintenance regime, including formal training of personnel to carry out any necessary repairs & regassing.

The decision to get rid of these gas tensioners from Sydney's OHW system primarily came about because of:

- The large number of units leaking gas and oil,
- The uncertainty of whether other individual units were actually performing (or were instead non-functional), and
- The special training and considerable ongoing maintenance requirements of a "pressure vessel".

REPLACEMENT

All *gas tensioners* were replaced around 2010 with standard *weight tensioners* installed in the open areas of the various ESR viaducts.

This is considered a good outcome, especially in terms of the much reduced future on-going maintenance effort involved with *weight tensioners*, as well as the confidence that they're accurately performing this vital function.

3.4.3.6 Status (c. 2014)

The use of any new gas tensioners in a project is subject to approval from Electrical Standards.

Because of significant on-going maintenance problems, all existing gas tensioners in the Eastern Suburbs Railway were removed in 2010. There are likely no more gas tensioners installed in the electrified network.

3.4.3.7 Reference

See *Table 31* for drawing reference.

3.4.4 Spring Tension Regulator

3.4.4.1 Description

The spring tension regulator is a relatively simple device that was developed locally (as I was once told). It consists of a large coil spring with "hairpin" type connectors which passes through the centre of the coil spring and which places the spring in compression. It connects the terminated catenary or contact wire (via termination insulators) to the anchor structure. Refer to *Figure 368* for example.

A spring tensioner takes up relatively small space, and so can be more readily utilised (subject to their reduced performance) at locations where the space requirements of standard weight tensioners make them impractical.

They are not considered to be true tension regulators – they only try to prevent the wide tension variations with temperature.

Note:

> Newer overseas designs seem to incorporate a clockwork-type spring housed in a shallow cylindrical container for compactness. This type shows much promise and thus may be accepted in future for certain circumstances, but at the time of writing they were not installed in Sydney's network.

The following description focuses only on the first type of (crude) spring tensioner. It is likely they have all been removed from service by now.

3.4.4.2 Function

Spring tensioners attempt to keep the conductor tension relatively constant by taking up the slack in the wire when hot, and by allowing the conductor to contract in the cold.

When hot, the spring expands when the tensioned wire lengthens, thus maintaining a degree of control over the tension. The opposite happens when cold.

I understand that they were rather limited in terms of their ability to effectively tension long runs of OHW, so they had been relegated to relatively short tension lengths, such as encountered at crossover runs.

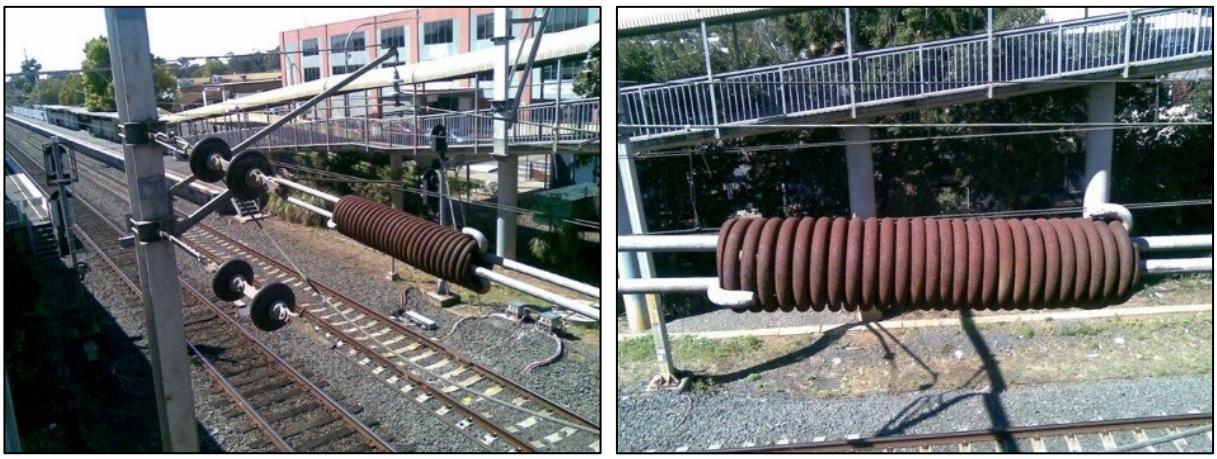


Figure 368 - An old Spring Tensioner

3.4.4.3 Typical Components

The spring tensioner is a relatively simple device. The main components are the spring itself, some "hair-pin" linkages that place the spring in compression, termination insulator/s and the

other mechanical parts needed to connect the anchor on one end to the OHW conductors at the other end of the spring.

3.4.4.4 Configuration

Spring tensioner units rely on the ability of a spring to expand or contract in response to any change in OHW conductor length (under the influence of the conductor's temperature). They are only effective for fairly short tension lengths (about one hundred to three hundred metres), in such situations as crossover wire runs.

Figure 368 shows a unit tensioning only the catenary wire. It was likely more important to have the catenary wire maintain its profile, and in doing so, keep the overall contact wire from sagging too much at mid-bay, and particularly at the various crossover forking-in points.

The spring tensioners that were installed many years ago in the electrified system were probably locally designed and made. They consisted of a truck spring (or the like) and 2 hair-pin steel rods (one installed at each end of the spring and rotated 90° to each other). This placed the spring in compression.

I understand that, being in compression this way, if the spring breaks then it's less likely to bring the OHW down. Instead, the spring collapses and is trapped by the 2 opposing hair-pin rods. The consequence is that the OHW loses a bit of tension and becomes fixed-anchored until the situation is corrected. Hopefully this doesn't affect train operations in the meantime.

3.4.4.5 Design Notes

LIMITS

These rudimentary spring tensioners were probably an attempt to try to maintain the tension in short crossover runs only, which is an admirable aim.

The main down sides to this device are listed below:

- The spring tensioner needs to be designed to suit a particular tension length (which needs to be fairly short), or it won't be able to maintain the correct design tension.
- Its ability to keep the design tension is nowhere near as accurate over the temperature range, or as reliable as, the standard weight tensioner arrangement.
- Over time, the high-strength steel in the spring suffers from "creep" which eventually reduces its tensioning characteristic. The photo shows that the spring was almost totally compressed (collapsed), and when this happens it acts more as a fixed-anchored system, which is obviously detrimental to providing reliable train services.

NEW DEVICES

There are modern spring tensioners available these days that are far more sophisticated and likely a lot more reliable (e.g. Pfisterer "Tensorex C+").

I may be wrong, but I think these devices can still only handle fairly narrow ranges of tension lengths, and they need to be tailor-made for the particular run length, which seems to be their one main draw back. This limitation may change with improvements made in time.

3.4.4.6 Status (c. 2014)

The simple old style spring tensioner arrangement described here is no longer being used.

3.4.4.7 Reference

Nil

3.4.5 Fixed Mid-Point Anchor Arrangement

3.4.5.1 Description

The "fixed mid-point anchor" ("FMP") is used in a regulated OHW system at a location near the middle of a run of OHW that has tension regulators located at both ends of the run.

3.4.5.2 Function

The fixed mid-point anchor "fixes" (locks) the catenary wire, which in turn locks the contact wire/s, to prevent them from drifting in the longitudinal (along-track) direction, without the need for physically terminating these wires.

The fixed mid-point anchor forces the tension regulators at both ends of the wire run to behave correctly as the temperature changes. If the fixed mid-point anchor was to be omitted, then the tension regulators at one end and/or other end would likely bottom out or jam at the pulleys. And the extra wire movement could also cause incorrect contact staggers throughout the run. In other words, without the FMP the OHW character can be somewhat unpredictable.

This arrangement is sometimes referred to as simply a "mid-point anchor", but its function is more about "fixing" the longitudinal location of the conductors at a particular point, than that of being a true anchor (which instead would take the full tension load).

Normally, the sorts of loads being "anchored" with the FMP are just conductor out-of-balance loads of roughly 1kN or so. The equipment used is typically not designed to handle the full wire tension (but consideration should be given to the possibility of a catenary wire snapping).

3.4.5.3 Typical Components

In addition to simple anchor guys and anchor blocks, typical components include:

- Anchor bridle wires (typically a single 165mm² copper catenary wire).
- Anchor insulators (for anchoring the bridle wires, but not at full tension).
- Catenary clamps to lock the anchor bridle wire to catenary.
- Catenary-to-contact bridle wires (90mm² [91/1.12mm] HD cu wire to each contact wire).
- Catenary and contact parallel feeder clamps.

3.4.5.4 Configuration

Fixed mid-point anchors are often installed in regulated OHW to provide a cost effective approach by the utilisation of long runs of OHW. Their application can be seen further back in the 2nd top run of *Figure 41*.

A tension regulator can be installed at both ends of a long wire run (the maximum OHW conductor length is approximately 2,000m), provided that a fixed mid-point anchor is installed somewhere near the middle of this wire run. This is done to prevent the catenary and contact wires from drifting, which could otherwise lead to:

- Malfunction of the tension regulators (weights bottoming or jamming into pulleys), and
- Unacceptably large movement of the supporting cantilevers, resulting in unacceptable contact wire staggers as the pull-off arms swing excessively and unpredictably. (The maximum tension length from tension regulator to fixed mid-point is limited to 1,000m partly because of this contact stagger deviation problem, even when properly controlled.)

The typical mid-point anchor arrangement has an independent *anchor bridle wire* attaching to the catenary and anchoring at the 2 adjacent structures – this fixes the catenary from moving. Refer to *Figure 369* for this and other parts.

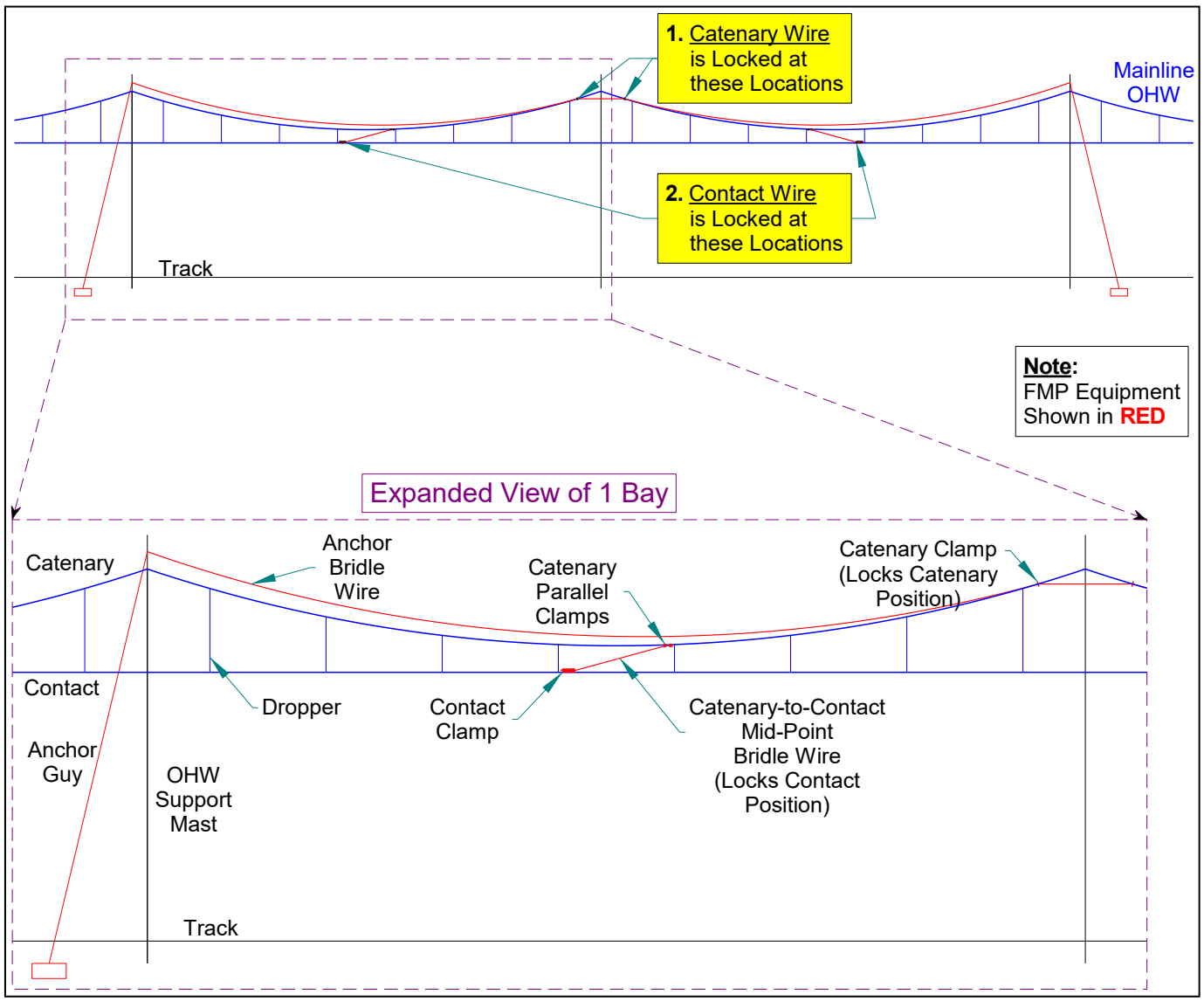


Figure 369 - Typical Fixed Mid-Point Anchor arrangement

The "catenary-to-contact bridle wires" are typically 90mm² copper wire. They attach from catenary down to each contact wire and should be ***at a shallow angle***.

This equipment is mirrored on both sides of the actual mid-point structure location, to control the contact wire movement See *Figure 371*.

Figure 370 - Fixed Mid-Point (Gosford to Newcaste)

In addition, each catenary-to-contact bridle also provides the function of an in-span feeder.

The two sets of bridles are required for securing the contact wire from movement in both directions (towards Sydney and away from Sydney). This is because the catenary-to-contact bridle can only work when in tension (it's a directional anchor and would simply go slack otherwise).

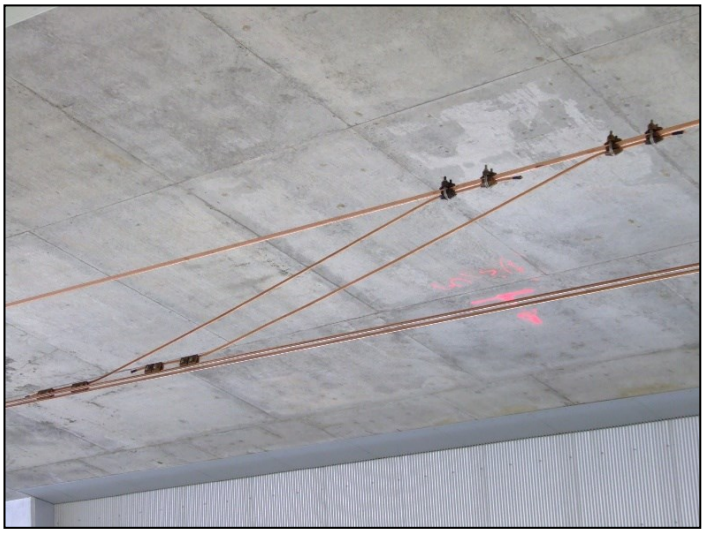


Figure 371 - Typical Catenary-to-Contact Bridles

FMP anchors are regularly installed at overline bridges (OLBs), in part because the system depth (height from catenary to contact wires) is shallow, which causes the catenary-to-contact bridle wire to have a ***very shallow angle***, which is a good thing in terms of not disturbing the contact wire profile in the bays. Refer to *Figure 372*.

An FMP anchor can also occur at a bridge, if the catenary wire can be directly clamped to an L-iron or T-iron, which itself is rigidly supported at both ends by a post type insulator (*Figure 372*).

Sometimes the FMP anchor is located at both ends of narrow bridges. This method required a correct initial setup, and relies on some flexibility of the L-iron or T-iron in order to maintain regulated tension in between these locations (to a degree).

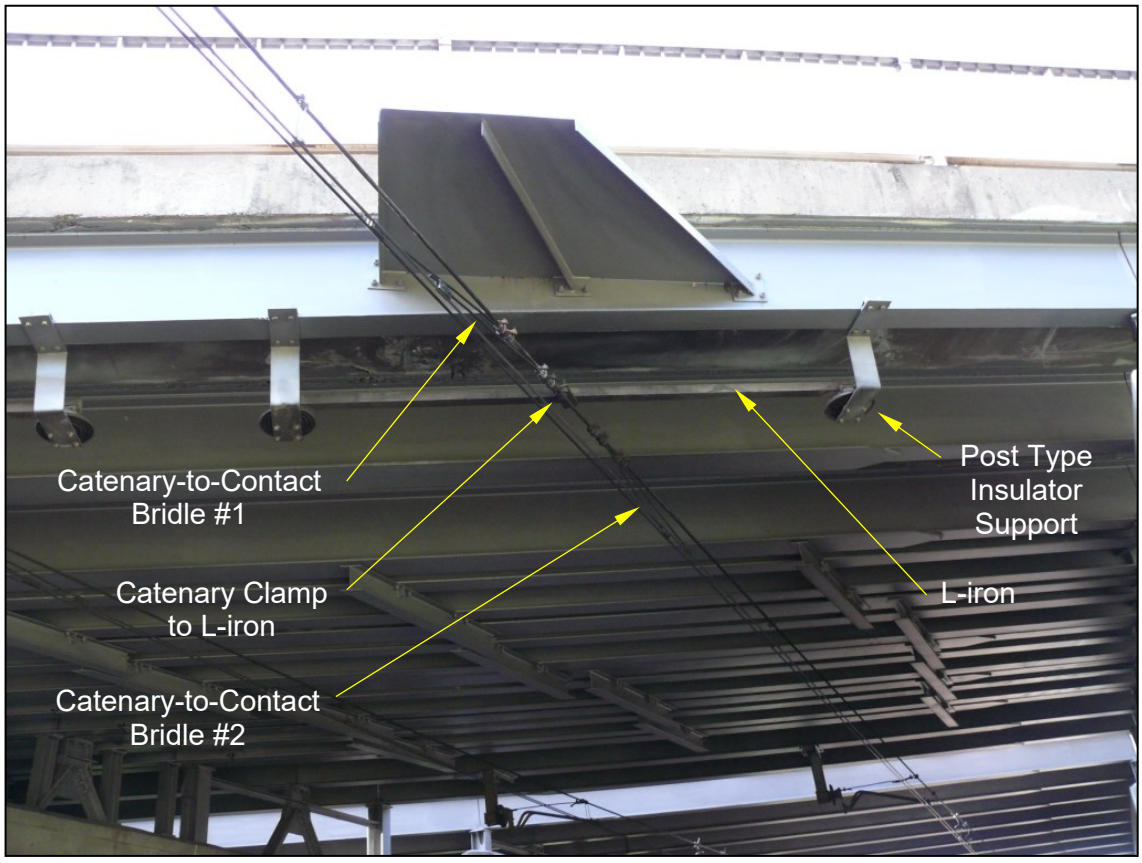


Figure 372 - FMP at an Overline Bridge

A less common (and to me, also somewhat less desirable) fixed mid-point anchor arrangement utilises 2 post type insulators in series, bolted to the underside of an appropriately sized portal bridge. Refer to *Figure 373* for example. This is typically used in multi-track situations where it would be difficult to locate the multitude of anchor bridle wires and associated guy wires that the normal arrangement would otherwise require.

In this case, the catenary is rigidly held to the lower end of the bottom post type insulator. With catenary saddle clamps installed snugly on each side of the catenary butterfly clamp, this fixes the catenary from moving in the longitudinal direction (but it can also place quite a strain on the insulators). The 2 insulators are used in series to help prevent lightning flashover and subsequent damage at this crucial point.

In this case, the OHW structure needs to be suitably designed to take the ever-changing out-of-balance conductor loads imposed on it.

Figure 373 - Multi-track FMP arrangements (with double insulators)

Some of these twin post type insulator arrangements include a pair of side strain insulators and span, to take any significant catenary radial load off the twin post type insulators (especially on curved track). This is done in an attempt to minimise the bending moment and other stresses on the post type insulators. Refer to *Figure 374*.

Figure 374 - Span Wire to take Radial Load away from FMP Post Type Insulators

However, there should ideally be a turnbuckle in the span in this standard arrangement, to allow the radial load to be more effectively transferred away from the insulators and better controlled. (I have seen some span wires sagging, meaning that it's taking no radial load and is thus performing no function at all.)

But the big disadvantage is that the catenary-to-contact bridle angle is quite steep, which is more likely to affect the contact wire profile to its detriment (for running fast trains).

Figure 375 - Fixed Mid-Point Anchor installed under concrete structure (at Chatswood)

Of course, there are also situations where the catenary wire has been cut and terminated through termination insulators onto both sides of a portal structure bridge. Refer to *Figure 376*.

This is probably more expensive, and the OHW structure needs to be sized to cope with the resultant loads, especially if conductors break. But this arrangement would have been required for some significant reason (you would hope).

Figure 376 - Terminated Catenary at an FMP

3.4.5.5 Design Notes

ANCHOR BRIDLE TO CATENARY

The 165mm² anchor bridle wires on each side of the FMP are installed as fixed-anchored wires, so their tension and sag change with temperature. A large amount of such sag can be a problem.

The amount of sag also changes if the catenary wire wants to drift in a certain direction. This leads to more sag in the anchor bridle bay where the catenary drift occurs, and less sag in the other anchor bridle bay.

Apparently there have been situations in the past where a low tension in this bridle wire caused the wire to go so low as to be struck by pantographs. This situation should be checked out, especially if the locked catenary drifts markedly in one direction causing the anchor bridle in that bay to become slack but the bridle in the other bay becomes taut!

Ideally the anchor bridle wire should have very little sag in the first place, so that it cannot become slack in any one bay. This ensures the catenary remains more effectively locked from longitudinal movement. In other words, the more the bridle wire tension is (or the less sag there is), the more the catenary position is actually "locked" from movement.

CATENARY-TO-CONTACT BRIDLE

The catenary-to-contact bridle is normally made from 90mm² (91/1.12mm) HD copper.

It acts to lock the contact wire from moving relative to the catenary wire (which in turn is rigidly held by anchors). It can only prevent contact movement in one direction and can do this if there's tension in this bridle wire. So, a bridle wire needs to be installed on both sides of the catenary anchor point, to restrain the contact wire movement for both directions (to Sydney and away from Sydney).

The large number of strands (91) was probably chosen to minimise the chance of fatigue at the catenary and/or contact clamp connection points, which can experience significant stresses as the millions of pantograph passages lift the contact wire/s and move the bridle.

This catenary-to-contact bridle wire should be installed ***as close to horizontal as is practical***. This usually means installing the catenary connection at the catenary low-point in the bay. Refer to *Figure 372* for example. After all, it's the out-of-balance *horizontal tension* that these arrangements are trying to arrest.

If the angle of this bridle wire is steep it is less effective in locking the contact wire position. Instead it tends to lift the contact wire and adversely affect the flat contact profile when the contact wire tries to drift away from the catenary. This can cause problems for passing pantographs, notably when travelling at higher speeds.

Unfortunately, there are numerous cases in the field where the bridle angle is closer to 45°, and sometimes you can see the lifting effect on the contact wire profile at its bridle connection point. Most of the bad cases are where twin post type insulators have been installed under a portal bridge, making the catenary height higher than normal and so the system depth at catenary support is quite large. An example of this is shown in *Figure 373* – note the steep catenary-to-contact bridle wire angles at each of the 8 instances.

Importantly, this bridle wire must not sag below the underside of contact wire for obvious reasons. So, this wire needs to be installed reasonably taut.

TWIN POST TYPE INSULATORS FOR CATENARY SUPPORT

As mentioned previously, there are quite a few cases where the fixed mid-point anchor is installed for 4 tracks on a single substantial portal structure. In these cases, the standard arrangement drawing calls for 2 post type insulators mounted in series to lock the catenary wire from moving, and doing away with the need for bridle wires to anchor at both adjacent structures. This situation relies on the strength of the insulators and the (double channel) portal structure itself, and likely aided with 4 guy anchors (one on each side of each portal leg).

The twin insulators are apparently needed to improve the lightning flashover performance, so that this important location doesn't become a weak spot and fail. This has to do with the principle of *graded insulation* (see *Section 5.1.7.2*).

There are other locations where 2 post type insulators are instead used in parallel, such as those shown in *Figure 375* and *Figure 379*. This configuration gives the arrangement incredible mechanical strength to resist any out-of-balance conductor forces experienced at an FMP arrangement.

In this case the lightning flashover is less than that of 2 insulators in series. However, these arrangements are usually installed at locations where the chance of lightning striking the OHW and flashing over at this point is much reduced or nil, e.g. inside a tunnel, or when surrounded by tall structures (acting as targets to lightning), etc. If lightning did trike the wire outside a tunnel, there would likely be other opportunities for equipment to flashover before reaching an FMP inside the tunnel.

Even a surge arrester protecting cables (e.g. at a switch or feeding point) on the same line and in the vicinity, can act to reduce the likelihood of flashover here.

SPECIAL FMP ON SYDNEY HARBOUR BRIDGE

The requirement to renew and regulated the OHW across the Sydney Harbour Bridge around 2010 meant finding a suitable place to install a fixed mid-point anchor arrangement for both tracks, somewhere on the bridge itself. Surprisingly, the steelwork of the bridge between the North Pylon and South Pylon (exclusive) moves quite a bit with temperature, and there are a number of expansion joints on each rail track to help accommodate the daily movement without affecting train services. (Apparently this movement also makes accurately surveying various parts of the bridge a very difficult exercise.)

It was decided the optimum location for the fixed mid-point anchors was at the North Pylon, as this huge stone structure provided something that didn't move with temperature. It was also something substantial in which to anchor the small out-of-balance loads that may result as the wires settle each day. It also meant that the OHW cantilevers supporting both runs across the bridge would be better controlled under any temperature induced bridge movement (the bridge supports the cantilevers). Refer to *Figure 377* for the somewhat unique arrangement that was needed to provide this anchor point.

The FMP occurs across 1 bay (for each track.

Here, the key to its effectiveness lay in the proper positioning and clipping of the crossing anchor bridles to the twin catenary wires at both ends of the single bay, so that the bay itself wasn't robbed of its correct catenary tension. This is very much like the fixed mid-point anchor situation at many overline bridges that have the catenary locked at both sides of the bridge (on L-irons) and with the single bay in between behaving quasi-regulated.

Catenary-to-contact bridles are installed as per standard arrangements.

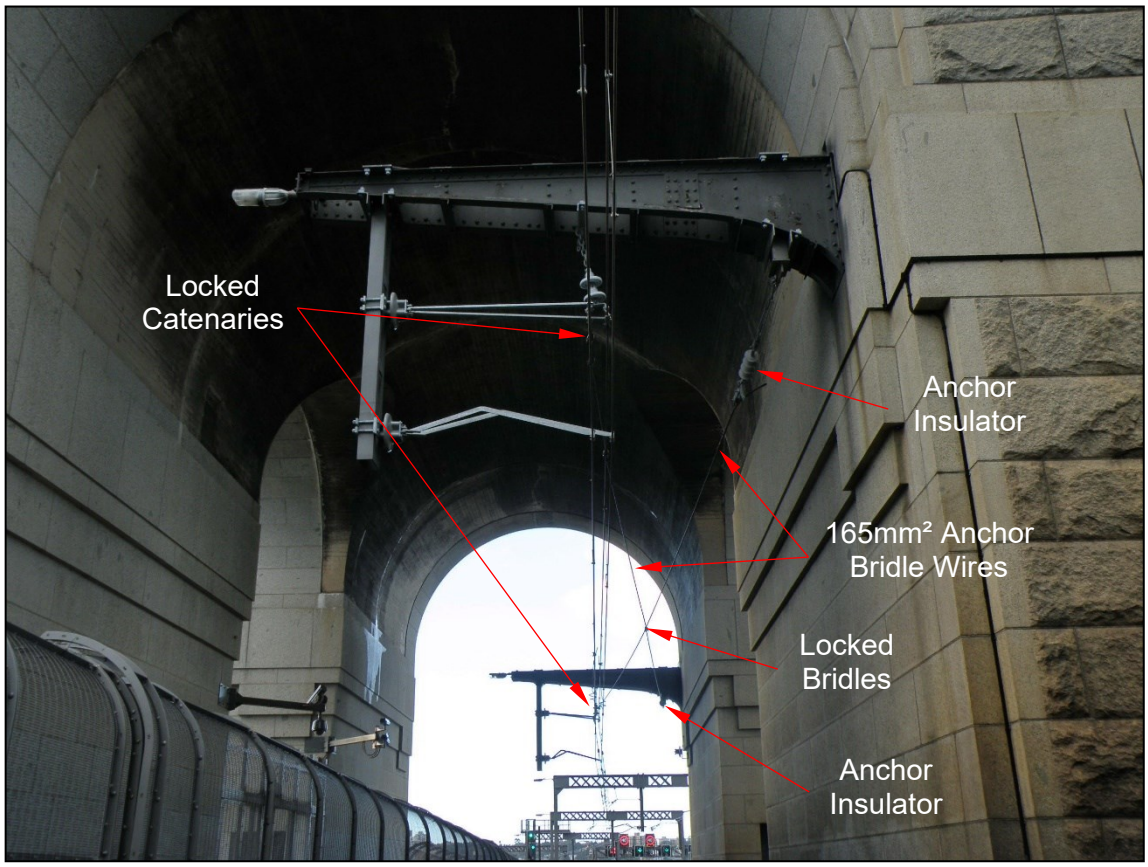


Figure 377 - Fixed Mid-Point Anchor (North Pylon, Sydney Harbour Bridge)

Figure 378 shows the anchor bridle wire connections to the twin catenary wires that lock them from moving longitudinally.

The second anchor bridle locks the twin catenaries at the other end of the bay so that they cannot drift in either direction.

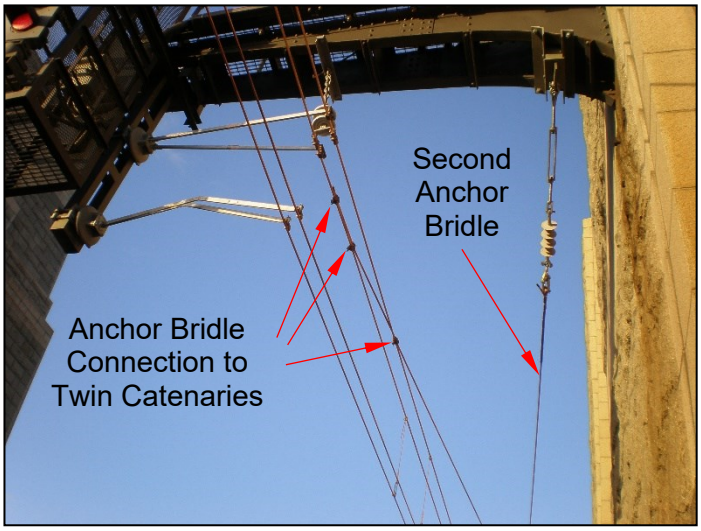


Figure 378 - Anchor Bridle to Catenary connections

SPECIAL FMP IN SINGLE TRACK TUNNELS

About 2km further north from the two fixed mid-point anchors on the Sydney Harbour Bridge (mentioned above) is another unique FMP anchor arrangement. It's installed just inside each of the 4 tunnels at North Sydney Station for the (then new) regulated OHW. *Figure 379* shows one such instance located on the Down Shore track. The other 3 instances are for the other 3 tracks at the same location.

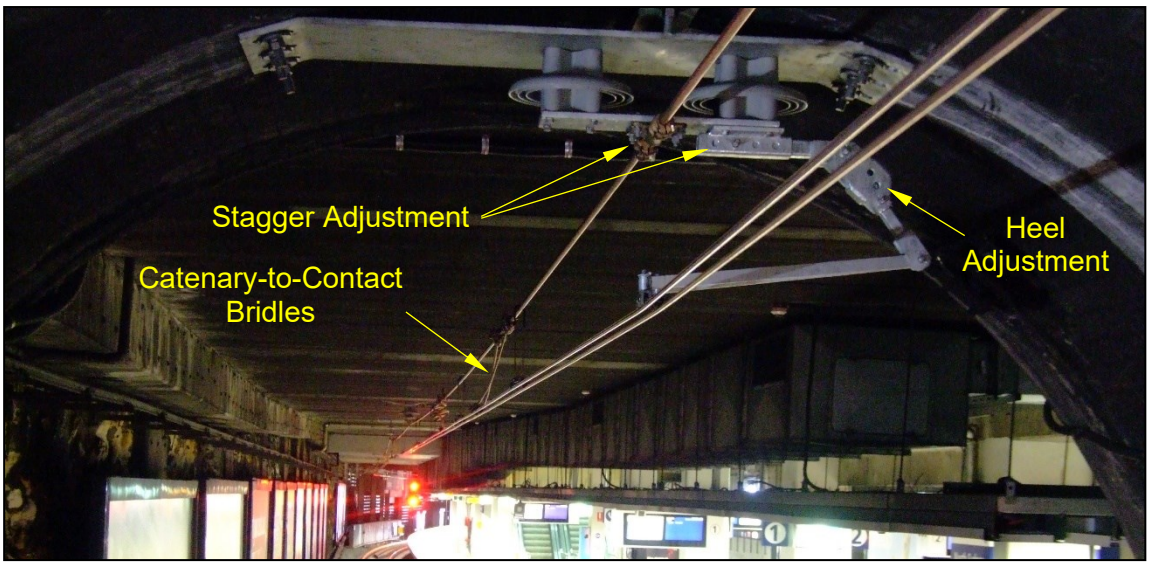


Figure 379 - Tunnel Fixed Mid-Point at North Sydney

The extremely small space above a train in these "breadloaf" tunnels required a compact arrangement that locked the catenary wire. It then relied on the classic catenary-to-contact bridles on both sides to further lock the twin contact wires from movement in both directions.

The catenary anchor is relatively straightforward, with a substantial steel plate anchored to the tunnel ceiling at several points. There are 2 post type insulators attached and supporting a steel plate underneath with "Swiss cheese" holes to allow attachment and adjustment of the catenary "butterfly clamp" which holds the catenary in place. The catenary is then locked from longitudinal movement by installing catenary saddle clamps snugly on each side of the butterfly clamp, which is common practice for this type of configuration.

The bigger challenge was to provide some suitable contact registration arrangement that has convenient horizontal adjustment (for stagger) and vertical adjustment (for heel height), and with each in 50mm increments. Fitting 185/3 was the result – see *Figure 380*.

The horizontal adjustment was straightforward, with 4 holes in an external/internal tube arrangement.

However, for the vertical adjustment, a special configuration was developed using external side plates with 1 pivot hole and 3 adjustment holes for 3 vertical heel positions 50mm apart. Two telescoping tubes fit between these plates. One 16mm SS pin is installed to allow these tubes to rotate near the top. The 3 other side holes are designed so that they only line up with the holes in the 2 telescoping tubes (for pin insertion) when 0mm, 50mm or 100mm *vertical* "heel position" is achieved. This fitting maintains good electrical clearance to the tunnel lining as required.

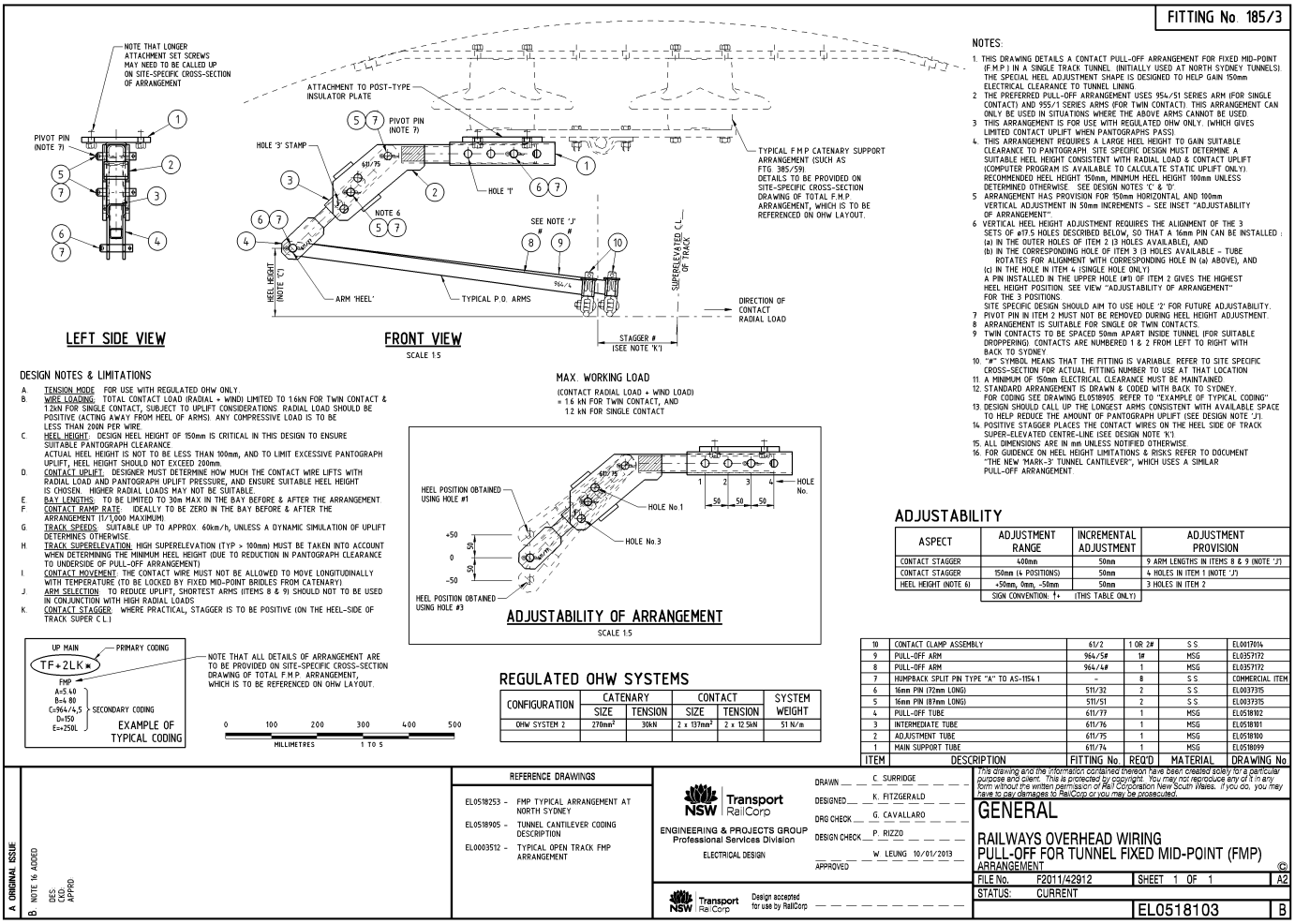


Figure 380 - Design drawing of Pull-Off for tunnel FMP

This arrangement has similar behaviours and restrictions as the Mk-3 Tunnel Cantilever, which was also developed for regulating the new OHW here inside North Sydney Tunnels.

TENSION LOSS IN REGULATED OHW

In a regulated OHW system, the maximum tension loss occurs at a fixed anchor or fixed mid-point location.

See *Section 3.4.0.5*, *Tension Loss* for more information.

3.4.5.6 Status (c. 2014)

The preferred mid-point anchor arrangement utilises the catenary anchor bridle wires to adjacent anchors.

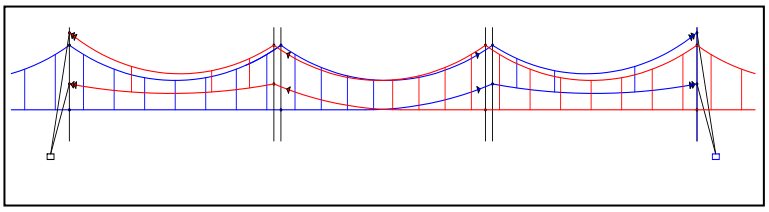
The mid-point anchor arrangement utilising twin post type insulators in series should only be used in situations where the above preferred arrangement cannot readily be installed. But care needs to be taken to keep the resulting catenary-to-contact bridle wire angle shallow.

There are other special locations that may need their own arrangement designed on a case-by-case basis, e.g. overline bridges, tunnels, etc.

3.4.5.7 Reference

See *Table 31* for drawing reference.

3.5 OVERLAPS



3.5.0 General

3.5.0.1 Description

On main lines, when one wire run of OHW ends it must be continued by another wire run, and the interface area where this usually takes place is called an "*overlap*". (These days, wire runs are limited to about 2km, but can be much less depending on track curvature, etc.)

Overlaps appear as 2 runs of OHW in a zone typically covering 3 or 4 bays (including both sets of anchor wires), where one OHW run is progressively taken over by the next run. This allows a smooth pantograph transition and current pickup, without any electrical arcing or disruption, from one wire run into the next.

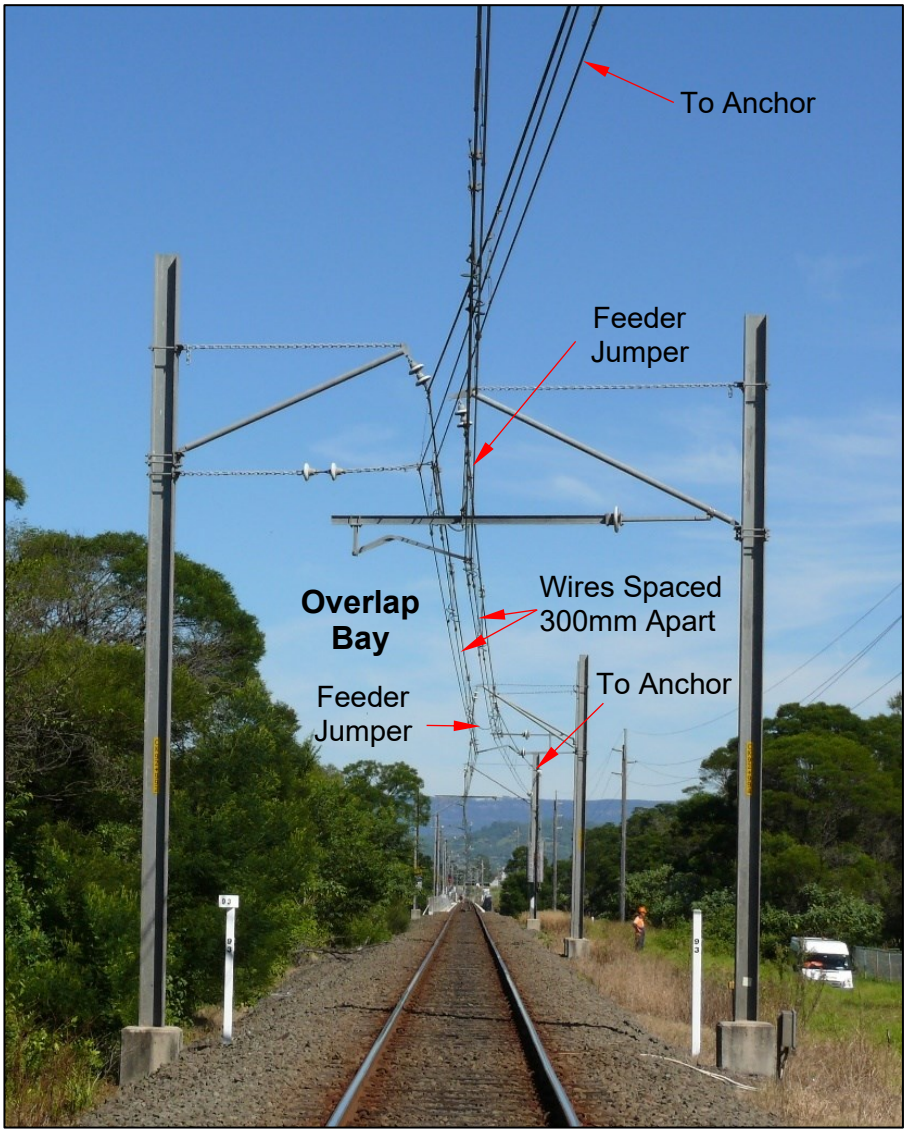


Figure 381 - View showing the parallel wires in an Overlap Bay

Figure 381 is a photo taken during the Dapto to Kiama Electrification Project, which shows a *non-sectionable overlap* (due to the omission of any out-of-running pennant insulators). It comprises a single overlap bay and an anchor bay at each end (forming a 3-bay overlap). You can just make out the 2 feeder jumpers needed for passing current from one run to the next. (I note the very large out-of-running contact height in the foreground here – not sure of the reason for this – it may just be an illusion.)

Note:

The term "airgap" is an older term referring to a "feeding overlap" located outside a substation or sectioning hut.

These days the term "overlap" seems to be preferred, as it can more consistently describe the 3 basic types of overlap situations:

- ***Feeding overlap*** (was "airgap") *or* ***switched overlap***,
- ***Sectionable overlap***, and
- ***Non-sectionable overlap***.

3.5.0.2 Function

The important action in an overlap occurs as the *contact wire/s* of one OHW run are progressively lifted up – going from "*in-running*" to "*out-of-running*" – while the run just next to it has the reverse happening. This take-over occurs within 1 or 2 *overlap bays*.

Overlaps can provide the following functions:

- They allow one OHW catenary and contact wire run to anchor and another adjacent run to take its place.
- They provide a smooth mechanical path for pantographs to collect current at speed.
- With appropriate contact staggers, they allow for pantograph security throughout the transition from one wire run to the next (in the "overlap bay"), even under extremely windy conditions.
- Their main role is to provide a smooth transfer of electrical energy to the pantograph (without arcing) from one wire run to the next.
- Overlaps can provide a reliable means of feeding or electrically sectioning (and rail-connecting) the OHW where required.
- They provide suitable electrical clearances from one electrical overhead wiring section to the next (if needed).

FEEDING OR SWITCHED OVERLAP

In terms of the OHW equipment and configuration, the physical makeup of a Feeding overlap and a Switched overlap are identical.

A *feeding* overlap is designed for feeding to 2 independent OHW electrical sections. This can allow for the discrimination of faults, and provide quick electrical isolation and protection of the OHW, through dc circuit breakers at the nearby substation or sectioning hut.

Alternatively, or additionally, *switches* can also be installed to conveniently isolate the sections, compared to the need to physically remove feeder jumpers (from one run to the next) every time. The switch can be operated by moving the switch handle vertically to the correct position.

Switches can be conveniently configured to:

- Electrically connect the 2 OHW electrical sections together,
- Isolate these sections; and
- Rail-connect one of the isolated electrical sections, if required. (2 such switches, when electrically interconnected, can rail-connect each of the 2 electrical sections individually.)

For more information on feeding to the overlap, either from a substation (S/S) or sectioning hut (S/H), or from a local switch arrangement, refer to *Section 3.7* (for switch arrangements) and *Section 3.8* (for S/S or S/H feeding).

SECTIONABLE OVERLAP

Sectionable overlaps provide the same functions as for the Feeding overlap, except that there is no external feed to the OHW. Instead, the 2 electrical sections in the overlap are

electrically bridged by feeder jumpers (FJs) to allow current to pass from one electrical section to the next in the overlap.

However, the 2 electrical sections can be separated if needed, by removing the feeding jumpers. Electrical clearances are designed throughout the overlap for this action to take place from time to time, and especially the parallel clearance between the 2 overlapping wire runs in the overlap bay (which is typically 250mm or 300mm horizontal spacing).

Note that the removal of the jumpers can take considerable time, and if isolation is a common need at a particular overlap location, it may be prudent to install switches instead of feeder jumpers.

NON-SECTIONABLE OVERLAP

Non-sectionable overlaps are simpler than Feeding or Sectionable overlaps, since there is no requirement to electrically isolate adjacent OHW runs in the overlap. So, the 2 runs are both always kept at the same electrical potential, i.e. either both alive at 1500 volts or both isolated from supply (and then usually rail-connected).

In essence, a non-sectionable overlap does not require any out-of-running pennant insulators (unless they are required for other reasons).

It is possible for the horizontal and vertical clearances between adjacent conductors to be reduced. However, there is usually little to be gained by changing these clearance parameters.

There is only one electrical section number needed when using this arrangement.

3.5.0.3 Typical Components

Overlaps basically apply other equipment types – namely "conductors", "support & registration", "support structures" and "anchors" – to form a configuration that allows OHW runs to be continued, which is a vital role in an OHW system.

So, the following components are common to most airgap and overlap arrangements:

- *Conductors*: catenary and contact wires (with their droppers), feeder and potential jumpers, pennant insulators.
- *Support & registration*: cantilevers etc. that hold the OHW conductors in a certain spatial position above a track.
- *Support structures*: to hold the support & registration arrangements.
- *Anchors*: to terminate and apply tension to the OHW conductors.

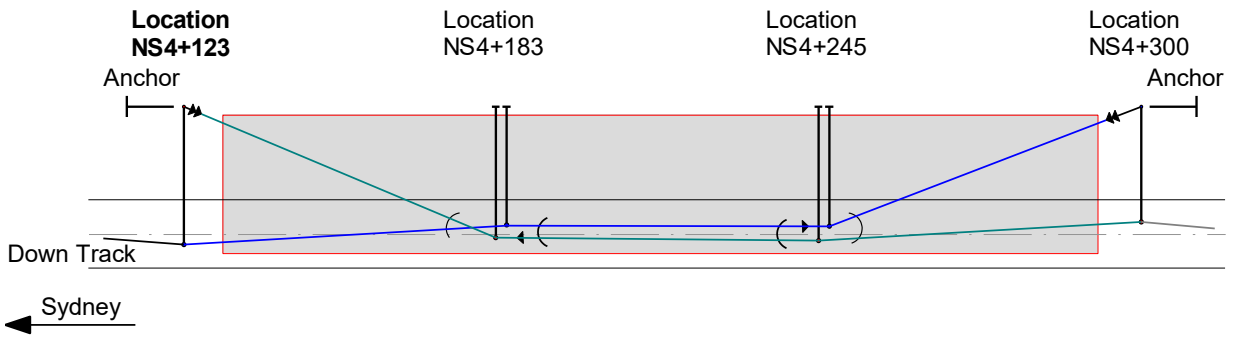
Figure 382 shows the basic typical configuration of an airgap/overlap, and its boundaries when referenced in an OHW system. See also *Figure 384*.

Overlap Arrangements

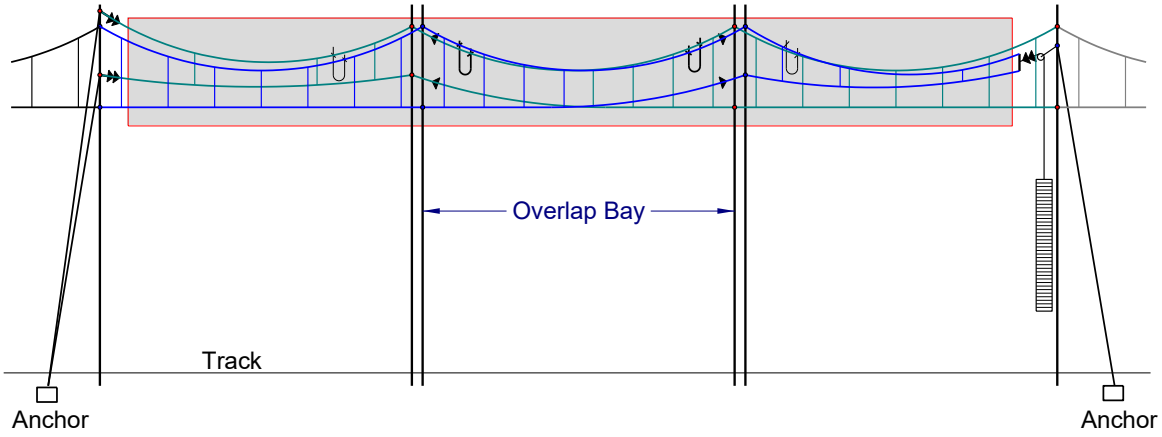
Overlap Arrangements

Asset
NS4+123, Down Track

Includes ... Feeding Airgaps
Sectionable Overlaps
Non-Sectionable Overlaps



Top View



Front View

Figure 382 - Overlap Arrangements - boundary

TMP Code	Equipment Name	Made By	Drawing No.
EP-08-26-00-00	**Airgap/Overlap Arrangements**		
EP-08-26-01-00	*Airgap Arrangements (for feeding to OHW)*	*RailCorp*	*K/82956 (e.g.)*
EP-08-26-11-00	*Sectionable Overlap Arrangements*	*RailCorp*	*K/82390 Sh. 1 (e.g.)*
EP-08-26-21-00	*Non-Sectionable Overlap Arrangements*	*RailCorp*	*K/82390 Sh. 1 mod. (e.g.)*
EP-08-26-31-00	*Non-Sectionable Contact-Only Overlap Arrangements*	*RailCorp*	

Table 33 - Overlap Arrangements

3.5.0.4 Configuration

Overlaps typically include 2 "anchor bays" (one at each end), and 1 (or sometimes 2) "overlap bays" in between these. So, this makes it either a "3-bay" or a "4-bay" overlap.

The "overlap bay" (or bays) is where the catenary and contact wires for both runs are parallel when viewed from above, and are spaced about 300mm horizontally apart for electrical separation.

The overlap bay/s have the contact wire of one run going from *in-running* to *out-of-running*, and the replacement run does the converse. The overlap bay is where all the action takes place. Refer to *Figure 382* and *Figure 384*.

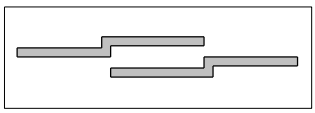
The term "airgap" seems to be an older term and applies to the specific situation where the 2 parallel sets of OHW conductors through the overlap bay/s are electrically isolated without feeder jumpers. So *airgap* applies to cases of feeding to the OHW – from substation or sectioning hut, or from local switches. I think it also applies to situations where the 2 sections of OHW are meant to be permanently isolated to prevent any long-term connection to independent supplies – forming an "open overlap".

So, overlaps can be "feeding" or "switched", or they can be "sectionable", or they can be "non-sectionable".

FEEDING OR SWITCHED OVERLAPS

Feeding overlaps provide external 1500V *feeding* to the OHW, and are sometimes called "feeding airgaps". This can apply to feeding at a substation or at a sectioning hut.

Operating Diagram Symbol:



The same symbol applies where there's local *switching* across the overlap. As with feeding overlaps, the actual connections would appear near this symbol on an operating diagram.

This symbol is also used in situations of "open overlaps" where the 2 electrical sections are totally isolated and remain so, with independent electrical supplies from further afield in the network. Note that this type of situation is relatively rare, as it can cause big problems if a pantograph parks under, and bridges out, the overlapping contact wires – see *Section 6.5.1*, *Relative Positions of Signals & Open Overlaps* for more details.

Appropriate horizontal and vertical clearances are required in the overlap bay, as the potentials of the adjacent parallel conductors throughout the overlap may differ by 1500 volts. (This typically requires a 250mm or 300mm horizontal clearance between the parallel wires.)

If there are 2 electrical sections in the overlap bay, they are (hopefully briefly) bridged out by each passing pantograph. This bridging would normally occur in the middle of the single overlap bay, and the "in-running" extent of bridged contact wires can be anything from as little as about 1 metre to 20m or so (depending on its site-specific overlap design). For a 4-bay overlap, the bridged portion usually happens in the area of the middle support locations common to the 2 overlap bays (see *Figure 383* for instance). In this case, the extent of pantograph bridging can be much longer, e.g. up to 40m or so (again depending on the site-specific overlap design). This longer in-running extent is primarily because the additional bay (2 overlap bays) gives more distance before the in-running contact wire needs to start rising out-of-running.

In feeding or switched overlaps, and also in sectionable overlaps, *pennant insulators* are installed in the out-of-running contact, and also directly above in the catenary. This serves the following purposes:

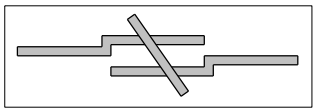
- Pennant insulators allow *adjacent* conductors to be at the same electrical potential, e.g. where the out-of-running wire crosses close to the in-running wire when heading off to anchor (see *Figure 384*, where the red & blue wires cross at the Sydney-end of the overlap in the Plan View). In this situation, a potential jumper (PJ) electrically ties the (otherwise isolated) wire going to anchor, to keep it at the same electrical potential as the adjacent in-running wire, consistent with the requirement that there be no "floating" sections.
- The tail of the terminated catenary wire at the pennant insulator can be used as an aerial feeder connection point for heavy current feeding from the substation or sectioning hut, or from a local switch. This is important because the electrical connection is then at a point where the catenary wire is not under any mechanical tension (as required by the standards). Any overheating of this heavy current connection caused by an imperfect joint is then not likely to cause a problem to the tensioned OHW.

SECTIONABLE OVERLAPS

These allow one run of OHW to be electrically disconnected from the next run if and when required. This can be achieved by removing the several feeding jumpers (FJs) installed in the overlap bay. But these overlaps have the necessary pennant insulators (as per the feeding or switching overlaps) to allow long term isolation and rail-connecting of one run of OHW while the other run remains alive, such as is needed during the maintenance of one of the runs.

If jumper removal was to be carried out frequently, then installing switches and permanently removing the jumpers would probably be economically justified – then becoming a *switched overlap*.

Operating Diagram Symbol:



Sectionable overlaps require the same horizontal and vertical electrical clearances as the feeding overlap (above).

Once the FJs are removed, *Electrical isolation* of the overlapped sections is achieved by:

- The requirement that there be 250mm to 300mm horizontal separation of both OHW runs of differing electrical sections in the overlap bay, and by
- The installation of pennant insulators at one or both ends of the overlap bay.

So, *feeding* from one electrical section to the next in the overlap bay, is provided by the installation of 2 or more U-shaped *feeder jumpers* from one catenary to the adjacent catenary in the overlap bay. These days, in-span feeder connections are also made from the untensioned feeder jumper down to the contact wires below, to help distribute the heavy

currents more uniformly and avoid overheating and annealing of any of the tensioned OHW conductors. More details on feeder jumpers can be found in *Section 3.1.12*.

Normally there are at least 2 heavy gauge feeder jumpers bridging both parallel catenary wires in the overlap bay. They are typically installed near the ends of the bay where the system depth is greatest. Some situations may require 3 or even 4 feeder jumpers, depending on the electrical load, OHW conductor configurations and the overlap bay length. The various standard overlap drawings show the number of feeder jumpers needed.

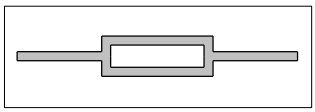
This is one of the few instances where it is acceptable to connect a feeder wire directly to the highly-tensioned catenary. However, it needs more than just one connection to help spread the load burden at the connection points, because any localised overheating will likely anneal the catenary at that point and weaken it until it snaps under tension. The same applies to the contact wire connections. (All conductors need to be properly cleaned before connection is made, and the connections have to be tight, to reduce the electrical resistance at the joint.)

So, the more feeder jumpers installed in the overlap bay, the less likely there will be annealing of the tensioned catenary and contact wires.

NON-SECTIONABLE OVERLAPS

These overlaps are not configured to allow any electrical sectioning described above, i.e. they simply allow a mechanical overlap of adjacent overhead wiring runs.

Operating Diagram Symbol:



The non-sectionable nature of this type of overlap means:

- No need for *pennant insulators*.
- Adjacent electrical sections are permanently jumpered using *feeder jumpers*. There is therefore no need for *potential jumpers* to be used.

There still needs to be an adequate number of feeder jumpers to cope with the OHW load current without annealing the connection points to catenary and contact wires.

Figure 383 shows a portion of a 4-bay overlap (Dapto to Kiama).

The closest mast pair is at the middle of the overlap arrangement. This is where both sets of twin contact wires are in-running for a considerable distance (i.e. 4 contact wires in running).

In the next bay, the left-side set of contact wires goes out-of-running and is supported at the next cantilever location (a Type 1G cantilever), then it finally heads off to anchor at the end of the 3rd bay in the distance.

Figure 383 - Middle of 4-Bay Overlap

So, there are 2 bays located behind the photo mirroring the same functions, thus forming the 4-bay overlap.

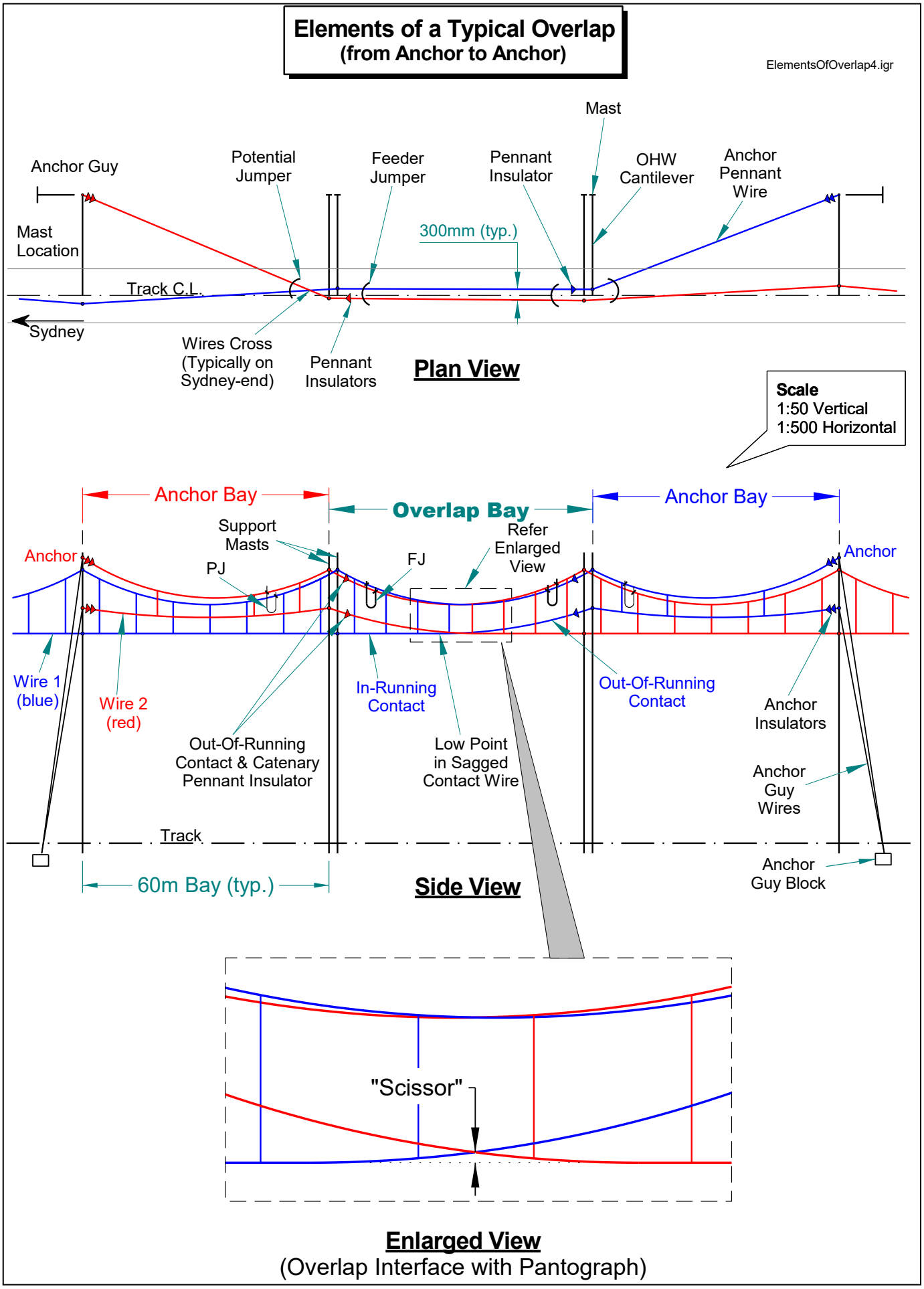


Figure 384 - Elements of a typical Overlap

3.5.0.5 Design Notes

CROSSING WIRES TO ANCHOR

With the anchor masts typically located on one side of the track, most overlaps need to have the out-of-running conductors (catenary & contact wires) and in-running conductors crossing at one end of the overlap only – either at the Sydney-end or at the country-end of the overlap. The other end of the overlap bay does not normally need to cross conductors when the OOR wires head off to anchor.

Refer to the *Top View* or *Plan View* in *Figure 382* or *Figure 384* – both these drawings show the wire runs crossing at the left end of the overlap arrangement (which is the Sydney-end).

Note however that there are some overlaps, particularly for single track, where the wire runs cross at both ends, and others where runs do not cross at either end. This typically happens where the anchor masts are located on opposite sides of the track (but not always).

The designer determines which end the crossing will occur. Certain projects, including Gosford to Newcastle Electrification, adopted a standard of crossing at the Sydney-end as the convention (wherever this was practical). Indeed, the current Electrification Standard states this same policy.

Because the catenary and contact wires of a particular run are vertically aligned with each other, if the catenary wire crosses the main line wire when heading off to anchor, so too does its supported contact wire.

MAIN REASONS FOR USING PENNANT INSULATORS

Feeding/switching overlaps and sectionable overlaps all require the overlap bay to have parallel wires with 2 different electrical sections.

The main purpose for installing pennant insulators at an overlap bay is to allow an out-of-running wire to cross close to the in-running wire when it needs to head off to anchor. In this regard it is particularly relevant to crossing catenary wires which can be as close as 50mm vertically apart (see *Plan View* and *Front View* at Sydney-end of *Figure 384*).

Without insulation, the crossing wires would need to be vertically separated by a minimum electrical clearance of 150mm. (It would need to be more likely 200mm or so if the 2 wires can move about e.g. due to wind or wire position changes due to longitudinal movement with temperature in a regulated system.)

For the contact wires, this sort of clearance can usually be attained in both the in-running and out-of-running wires where they cross, since the OOR wire is typically 350mm to 600mm higher than the IR contact wire for the overlap to work.

However, with the catenary it's much more difficult to get 200mm clearance where they cross.

So, by installing a pennant insulator into the OOR catenary wire, it can allow the wires to just have mechanical clearance where they cross – usually this is about 50mm. In this case, a potential jumper is installed between the in-running catenary and the catenary wire going to anchor, to keep both at the same electrical section (the catenary anchor pennant wire should never carry any heavy current in this situation). This solution greatly simplifies the problem.

Contact pennant insulators are installed in sympathy with the catenary pennant insulator above, and they need to be vertically in-line with each other.

Another clearance problem that's overcome when pennant insulators are installed is shown in *Figure 385*. This diagram shows one end of a Feeding / Switched or Sectionable Overlap,

where the OOR contact wires are at 600mm above in-running at the Type 1A/2A cantilever. Without pennant insulators installed, the *electrical clearance* between the Type 1A/2A horizontal boom and the OOR contact wires that pass above it would need to be at least 150mm, since they are of different electrical sections. This would require that the OOR wires be raised even more than 600mm, which would be impractical in an overlap design, requiring a very long Overlap Bay. But if pennant insulators are installed in the OOR wire, then this clearance can be reduced to simply *mechanical clearance* of 50mm or so. (Note that the 300mm odd OOR height of the Short Bay Overlap can have these OOR wires pass under the horizontal boom, which is a much simpler outcome.)

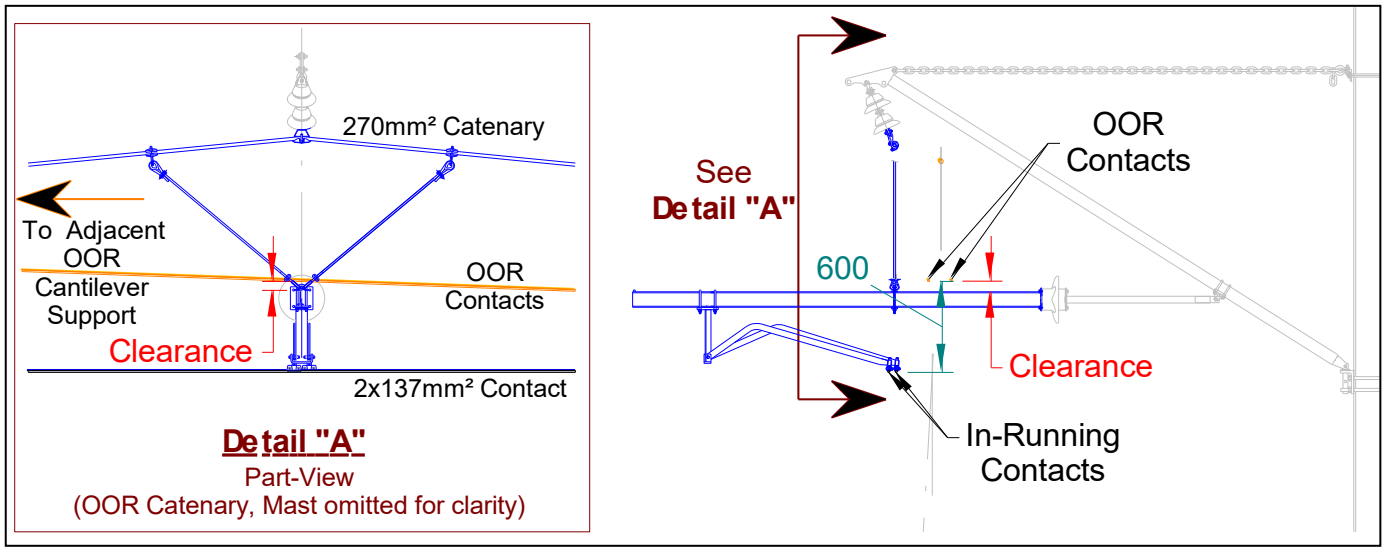


Figure 385 - Clearance from OOR Contact wires to Type 1A/2A Horizontal Boom

LOCATION OF PENNANT INSULATORS

In most cases of feeding/switched overlaps and sectionable overlaps, pennant insulators need to be installed somewhere in the overlap bay/s.

If pennant insulators are installed, they are located close to the out-of-running support location in the overlap bay. This is done primarily so that suitable vertical passing clearance can be obtained – from uplifted pantographs to the underside (skirts) of the out-of-running contact pennant insulator, per *Figure 386* further below. (A minimum of about 300mm vertical clearance is typically required.) The catenary pennant insulator is then located vertically above this contact pennant insulator.

Throughout the electrified network these pennant insulators can be installed:

- At one end of the overlap bay/s only (preferably at the Sydney-end), or
- At both ends of the overlap bay/s.

As described in the previous section, a pennant insulator installed at the end where catenary wires cross allows the out-of-running catenary to cross closer to the in-running catenary when going to anchor (typically only 50mm clearance is then needed). Catenaries normally don't cross at the other end of the overlap.

I think the main reason for having them installed at *both ends* is to maximise the work area when one run is isolated and rail-connected. This is so that more maintenance work can be carried out. It possibly gives them 1 more bay (the non-crossing anchor bay) to work on, before they then might encroach the hazardous zone – live equipment in the overlap bay. This might sound trivial, but access to the track is often difficult to get, so the more OHW that can be safely worked on, the better.

Refer to the current Electrical Standards regarding safe work area limits.

OVERLAP DESIGN

For some design details of Overlaps, refer to my document *"Fundamentals of OHW Overlap Design"*, dated 12/11/2002. (Note that this was produced some time ago and there may be some improvements made since then, so consult the current Electrical Standards for any changes to the design approach to overlaps.)

Recent observations, as well as the introduction of the Short Bay Overlap arrangement, have made me think there are some further improvements that could be made to the design of overlaps, particularly in terms of lowering the tolerable amount of "scissor" (explained below) for smooth pantograph transition from one wire run to the next. Any scissor amount can cause more pantograph uplift towards mid-bay, and with accompanying dynamic vertical wire movement. So ideally there should be no scissor, but this is not always readily achievable.

Fundamentals of Overlap Design

The below description briefly mentions the things that need to be achieved when designing overlaps. For more detail refer to the above document.

Reference will be made to *Figure 388* (a bit further on), which is provided to show the various important aspects that should be considered when designing overlaps in regulated OHW.

One wire run must end (for a number of reasons) and be taken over by the next wire run. The focus of this description is the contact wires only. (The catenary wires simply hold the contact wires at suitable heights and staggers as required.) I use contact wire in the singular form, although the OHW system these days is normally twin-contact. It helps understanding if just the single contact is referred to in the description below. (Twin contacts make things even better anyway.)

In the overlap bay, both runs of contact wires (and supporting catenary wires) remain parallel to each other (in plan view). The parallel separation is usually 250mm or 300mm.

For smooth take-up of the next contact wire, the in-running (IR) contact wire needs to remain in place in the bay until the contact wire of the next run can lower sufficiently from out-of-running (OOR) to in-running, to take its place. This change-over happens in the *overlap bay*. Sometimes in the past, 2 bays were required for this overlapping function, but these arrangements are less common now, and not necessary at all in future designs using the "Short Bay Overlap" arrangement – see below.

(*Note:* An alternative might be to use the approach that's used at turnouts, where the other wire is only 50mm above the IR wire, but this could easily be struck by the pantograph at speed if not carefully controlled, causing an unacceptable loss in reliability. And both runs would need to be of the same electrical section. But this is definitely not suitable for medium to high speed operation)

Importantly, in a lateral sense under extremely windy conditions, *pantograph security* needs to also be maintained throughout the overlap bay, including this overlapping transition area.

So, at both ends of a single overlap bay there's an IR and an OOR contact wire and the roles reverse at the other end of the bay. The OOR wires at the support locations need to be high enough to clear certain obstructions, including:

- The IR pull-off arm/s and other associated equipment, and
- Pennant insulators installed in the OOR wire near its support location. The lower side of the skirts of these insulators need to be well clear of any uplifted pantograph to avoid a clash (*Figure 386*).

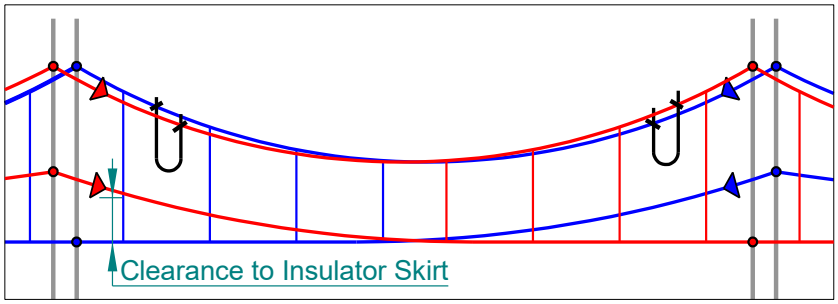


Figure 386 - Clearance to OOR Insulator Skirt

Up until the mid-1990s, the 254mm diameter of the pennant insulator (typically 453/12) in the OOR wire required the OOR contact height to be quite high at about 450mm or 500mm above IR. It increased further to 600mm in order to pass above the horizontal strut of the Mk-2, Type 1A & 2A cantilevers and gain suitable mechanical clearance in this situation.

In an attempt to prevent someone forgetting to add extra clearance for these Type 1A-2A cantilevers, the various standard overlap arrangement drawings between mid-1980 and mid-1990 required all OOR wires to be at 600mm above IR at the support location. This then always achieved the requirements in both dot points above. Refer to *Figure 385*.

However, the consequence of this extra vertical clearance was that the overlap bays needed to be very long. From 600mm OOR, it takes about 35m to bring this wire into running and another 35m to bring the other IR wire 600mm OOR. So, a 70m bay was required, but this is greater than the maximum bay length of 67m!

The solution to this conundrum was to accept some amount of "scissor" at mid-bay, where one wire can *begin* to rise before mid-bay, and be up to 50mm higher at mid-bay before meeting the other wire heading down to IR (also at 50mm higher).

The term *scissor* comes from the idea of a fully opened pair of scissors forming this sort of not quite flat shape (about 170°) because it can't be fully extended to 180°. See *Figure 387*.

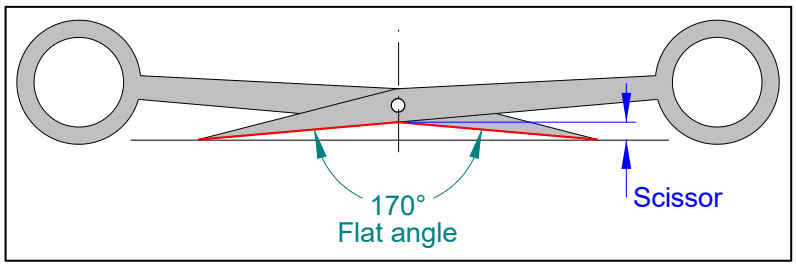


Figure 387 - Scissors showing shallow rise

The tolerable scissor amount was set at 50mm before 1980, and I think this is because it was thought that this is how much the pantograph typically lifts the regulated contact wire near mid-bay anyway. Unfortunately, the logic here is not perfect, because the pantograph will lift a *naturally sagging* contact wire (coming into running) even more than the 50mm figure because there's almost no wire weight to resist the upward pantograph force. But by then, there'll be another contact wire pressing onto the pantograph as this wire comes into running to replace the other wire. Anyway, this reasonable amount of scissor can lead to the contact wires moving about when fast pantographs (with their uplift force) pass through the overlap bay, which suggests a less-than-perfect arrangement (but should cause no long term problems anyway).

It takes about 10m for the contact to rise to 50mm, so this meant that the 70m figure above could reduce to 50m overlap bay, which is quite a practical result for normal Type 1 & Type 2 cantilevers handling track radius down to about 800m. Tighter track radius than this required a Type 3 cantilever, and these situations were deemed to require 2 overlap bays (a 4-bay overlap) in order to get the necessary distance to go OOR by 600mm.

So, an ideal overlap would have no amount of scissor, but this is the real world – see below.

The Short Bay Overlap

In 1996 a "Short Bay Overlap" arrangement was developed to help achieve better overlaps that required less equipment and could be installed in a shorter space. It relied on the optimising ability of the (then new) "Overlap.xls" spreadsheet program to design new overlaps, for all situations. (This approach was instead of referring to the several standard arrangement drawings available at the time, that didn't always exactly fit the site-specific situations.)

The main aspect of this arrangement was the inclusion of a more compact pennant insulator (the "Reliable" composite insulator, fitting 453/17). The out-of-running insulator diameter was reduced from 254mm of the 453/12 insulator, down to only 65mm (and the outer covering is made from silicone rubber, not hard and brittle porcelain).

This reduced insulator diameter and flexible covering permitted the OOR contact height to be halved from 600mm to about 300mm, which in turn catered for much shorter single overlap bays down to about 30m. Note that the contact wires by this stage were mostly under *regulated tension*, which behaved much better than *fixed-anchored tension* in terms of controlling pantograph uplift.

So in theory, a short bay overlap could be established just about anywhere in the system. This proved to be a huge benefit, that added much flexibility and at cheaper initial cost as well as ongoing maintenance costs (mainly because there's less equipment).

Tolerable Amount of "Scissor"

As mentioned above, the tolerable amount of scissor in an overlap bay was set at 50mm around 1980. This was around the time the standard design staggers and heights were established for the (then new) standard overlap arrangement drawings for Gosford to Newcastle Electrification Project that was under way at the time.

This task of designing standard overlap arrangements consumed much time as the numerous bay length / track radius combinations had to be analysed and suitable contact staggers and heights determined and documented. The knowledge gained from this process helped me to develop a spreadsheet tool in the late 1990s called "Overlap.xls", which is used for quickly and accurately determining suitable and optimum design staggers and heights for any one-off overlap situation having a single overlap bay only.

It is unfortunate that the 50mm scissor amount has consequences – as described above, the pantographs tend to rise at mid-bay, causing some additional vertical movement of the wire as the train passes through (and there are 4 pantographs to a typical 8-car set). This effect is particularly noticeable on long (60 to 67m) bays, and there were a couple of these installed in full view at our Sydney Trains Electrical Design offices when located at Burwood. Although it does no harm, it just looks strange having the overlap contact wires oscillate up & down by about 100mm or so as the train passes though the overlap.

Note:

Since the *short bay overlap* arrangement now only requires the OOR wire to be lifted up by about 300mm, there should be no reason to tolerate the 50mm scissor figure.

So, a much lower value of 10mm scissor (say) could be used, and in return provide a more dynamically stable pantograph / contact wire interface through the overlap bay, which would be a good thing. (Maybe this improvement could be incorporated into the standards in future?)

With 10mm scissor, it takes about 5m for the contact wire to rise 10mm, and about 25m for the contact wire to rise 300mm OOR. Accordingly, in theory, an overlap could be formed in a bay length of as little as 40m, which in turn corresponds to a track radius of about

450m, which is a very tight curvature indeed (it would be rare to need an overlap in this extreme situation).

Better still, if no scissor was allowed, this would require about 50m minimum overlap bay length, which would suit most practical overlap situations in the field.

RELATIVE LOCATION OF OOR CANTILEVERS

Interestingly, in about 1985 during the early part of the Illawarra Electrification Project (from Waterfall to Pt Kembla), it was decided to swap the relative placement of the out-of-running (OOR) cantilevers with the adjacent in-running (IR) cantilevers (2m away) in the 3 or 4 standard Overlap arrangement drawings.

For the previous major project – the Gosford to Newcastle Electrification (and probably a few others before it) – the OOR cantilevers at each end of the Overlap Bay were installed at the inner-most locations. However, for the Illawarra Project it was changed to have them as the outer-most locations.

We were told at the time that it was how the older fixed-anchored overlaps were configured, and this configuration seemed to have a few benefits. And so, it's been the standard in place since 1985.

All else being equal, this change in position provided a slightly longer Overlap Bay, making it slightly easier to get an overlap to work (in theory at least). And there may be other benefits too.

STAGGERS AT OOR LOCATIONS

Whenever an overlap is installed on curved track, and the in-running and adjacent out-of-running cantilevers are at different locations (e.g. spaced 1m or 2m apart), then an adjustment is needed in the OOR stagger value in order to deliver the important 250mm or 300mm parallel wire separation of the 2 wire runs throughout the overlap bay.

Example:

Refer to the overlap situation being modelled further on in *Figure 389*. This shows an overlap bay of 50m, above a track with 1,000m radius, and IR and OOR mast pairs installed 2m apart at each end of this bay. With 300mm horizontal wire spacing needed in the overlap bay, the Sydney-end IR stagger is 300mm but the OOR stagger needs to be set at 42mm (not 0mm) so that it becomes 0mm at the IR location 2m further along (= 300mm apart at that location).
At the other end with 200mm IR stagger, the OOR stagger is 558mm (not 500mm).
So, these corrected OOR staggers will deliver the required parallel 300mm wire separation throughout the overlap bay.

Overlap designs prior to the 1990s required some field adjustment to the OOR cantilever in order to get the correct horizontal separation in the overlap bay. However, the *Overlap* spreadsheet program developed in the 1990s (and detailed further below), accurately models this situation and determines, among other things, the OOR stagger needed to achieve the correct parallel spacing of the runs of wires through the overlap bay. No more need for the time consuming "adjust in the field" approach of the past (with its subjective approach and uncertain outcome).

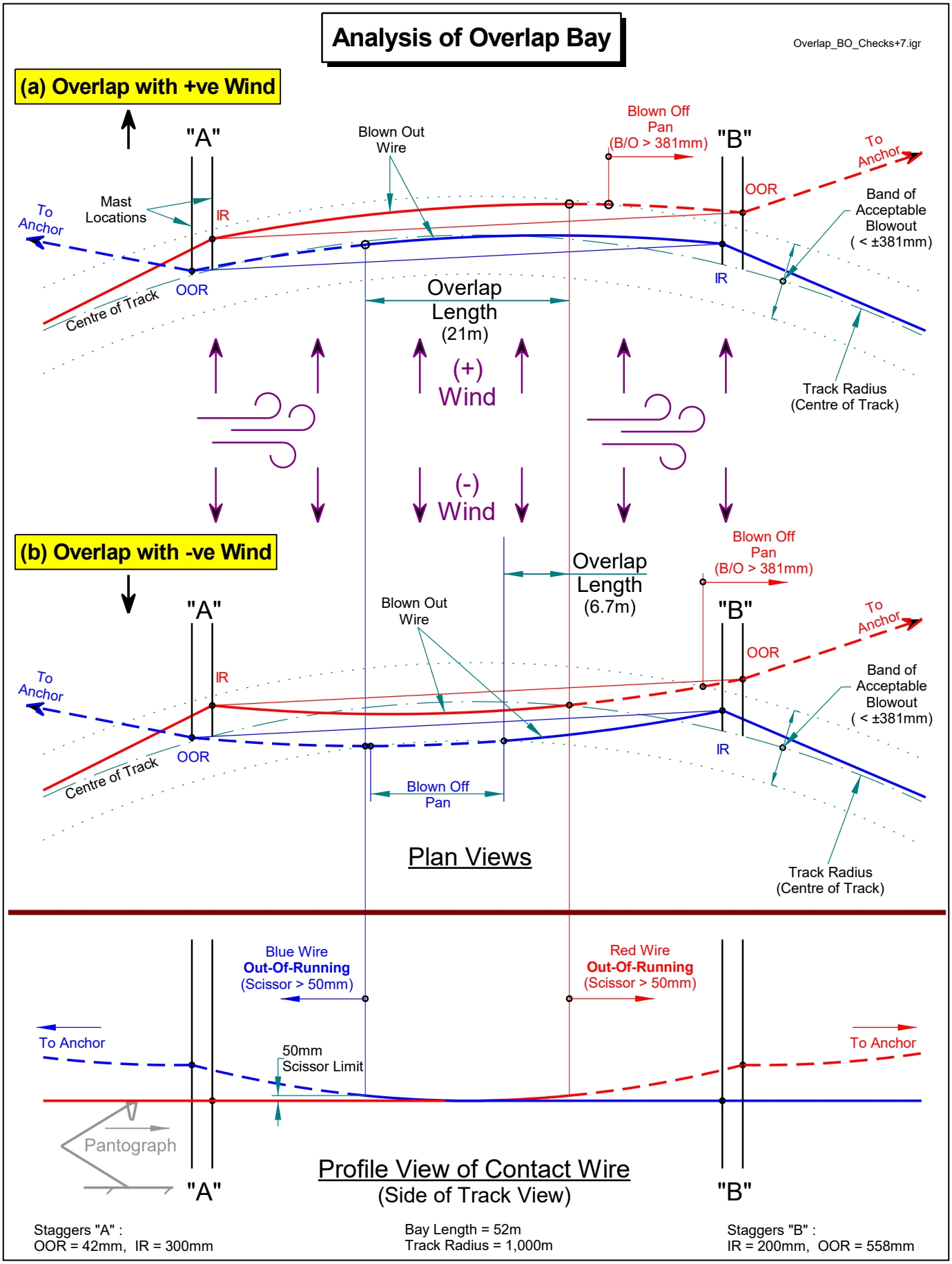


Figure 388 - Analysis of an Overlap Bay

THE "OVERLAP" SPREADSHEET PROGRAM

This program provides a fast, convenient and accurate way of determining various overlap parameters in the design of a workable site-specific overlap arrangement. And at the press of the "Calculate Optimum Staggers" button, the associated Visual Basic Macro also determines the optimal set of staggers that maximise the overlap length, where the pantograph rides along both sets of wires before one or other wire goes out-of-running. (Actually, there can be many sets of staggers that deliver the same optimum overlap, and they are tabulated on a separate sheet of the spreadsheet program for further reference and use.)

Refer to an example of the output in *Figure 389*, which shows the results that are drawn in *Figure 388*. The important cell is headed "Minimum Overlap", which should be a number greater than 0m for it to be considered a suitable design overlap (the example shows 6.702m).

The *system parameters* include:

- The incoming and outgoing contact wire sizes, their tensions, whether single or twin contact (and their diameters and weights/metre),
- Maximum blowout amount per the standard (e.g. 381mm),
- Maximum wind speed (130km/h).

The *overlap parameters* include:

- Horizontal wire spacing (typically 300mm),
- Tolerable scissor amount (typically 50mm),
- Overlap bay length,
- Track radius (needs to be a positive number),
- Spacing between mast pairs at each end of the overlap bay (e.g. 0m, 1m or 2m),
- The out-of-running rise at each end (typically 300mm or so)
- The 2 in-running staggers at each end of the overlap bay.

Given that most of the parameters are firm (adopted from the standards), the usual variables to be input (trialled) are the in-running staggers, and the result is the out-of-running staggers – quite simple, except that there needs to be some non-zero "minimum overlap" to be successful. The trialled variables can be entered into the non-coloured cells.

Usually the longer the *minimum overlap* length the better for pantograph interaction.

The exception is where it's an *open overlap* located within a certain distance on the approach side of a set of signals. This signal might cause a train to stop with one of its pantographs bridging the overlap for extended periods. This may in turn cause contact wire annealing problems if current feeds through the pantograph from one electrical section to the next. In this case, the shorter the overlap length the better, as it reduces the likelihood of pantograph parking under and bridging the overlap (in much the same way as a section insulator reduces this risk). See *Section 6.5.1*, *Relative Positions of Signals & Open Overlaps* for more.

In the example of *Figure 389* I have bracketed the "Length of Overlap" for both the +ve and -ve wind directions, to show how the Minimum Overlap is determined – this is also shown graphically in *Figure 388*.

Obviously there are many variables where numbers can be changed for a different modelled outcome. Hopefully the graphics in *Overlap.xls* make its workings self-explanatory.

There might be better ways of modelling the overlap these days to produce some optimum site-specific design, but this program has saved a lot of effort in the past, and has given a level of confidence that the overlap will work, even under the extreme conditions.

Overlap Security

Written by Ken FitzGerald © RIC
Version : 3.0 - 03/07/2002

Contact Details

Enter the following ...	Wire 1	Wire 2
Size (sq.mm.)	193	193
Number of Contacts	1	1
Tension (N)	18,000	18,000
=> Diameter (mm)	16.41	16.41
=> Weight (N/m)	16.89	16.89
Maximum Blowout (m)	0.381	0.381

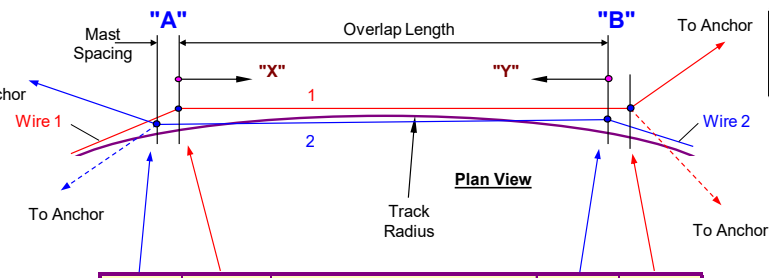
Copy-> <-Copy <-Swap->

Common Conditions

Enter the following ...	
Wind Velocity (kph)	130
Horizontal Wire Spacing (m)	0.3
Maximum Scissor (m)	0.05

Calculations ...

	Wire 1	Wire 2
=> Bay Length (m)	52.000	52.000
=> Versine (m)	0.338	0.338
=> Blowout (m)	0.192	0.192
=> Distance to Lowpoint (m)	27.313	27.313
=> (from other end)	24.687	24.687
=> Distance to Scissor (m)	10.323	10.323



Calculate Optimum Staggers

OOR	Loc "A"	Staggers	Loc "B"	OOR
	0.300	Wire 1	0.500	0.558
0.042	0.000	Wire 2	0.200	

Set these

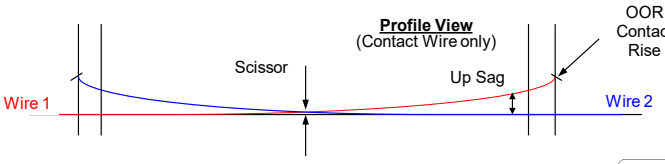
	2	Mast Spacing (m)	2
0.35	OOR Contact Rise Above In-Running Contact (m)		0.35

Minimum Overlap: 6.702

Overlap Length (m)	50
Track Radius (m)	1000

<= Note : Must be +ve !

Sign Convention: = "+" / = "-"



Rebuild Table

Distance "X"	Wire 1 + Wind	Wire 1 - Wind	Wire 1 Up Sag	Distance "Y"	Wire 2 + Wind	Wire 2 - Wind	Wire 2 Up Sag	+ Wind Wire 1	+ Wind Wire2	- Wind Wire 1	- Wind Wire2
-2				52	0.042	0.042	0.350	====		====	
-1				51	0.034	0.005	0.325	====		====	
0	0.300	0.300	0.000	50	0.026	-0.030	0.301	XXXX		XXXX	
1	0.294	0.265	0.000	49	0.019	-0.064	0.277	XXXX		XXXX	
2	0.288	0.232	0.000	48	0.013	-0.096	0.255	XXXX		XXXX	
3	0.283	0.200	0.000	47	0.006	-0.127	0.234	XXXX		XXXX	
4	0.278	0.169	0.000	46	0.000	-0.156	0.213	XXXX		XXXX	
5	0.274	0.141	0.000	45	-0.005	-0.184	0.194	XXXX		XXXX	
6	0.270	0.114	0.000	44	-0.010	-0.209	0.175	XXXX		XXXX	
7	0.267	0.088	0.000	43	-0.014	-0.234	0.157	XXXX		XXXX	
8	0.263	0.064	0.000	42	-0.019	-0.257	0.141	XXXX		XXXX	
9	0.261	0.041	0.000	41	-0.022	-0.278	0.125	XXXX		XXXX	
10	0.259	0.021	0.000	40	-0.025	-0.298	0.110	XXXX		XXXX	
11	0.257	0.001	0.000	39	-0.028	-0.316	0.096	XXXX		XXXX	
12	0.256	-0.017	0.000	38	-0.031	-0.332	0.083	XXXX		XXXX	
13	0.255	-0.033	0.000	37	-0.033	-0.347	0.071	XXXX		XXXX	
14	0.254	-0.047	0.000	36	-0.034	-0.361	0.060	XXXX		XXXX	
15	0.254	-0.060	0.000	35	-0.035	-0.373	0.050	XXXX	XXXX	XXXX	XXXX
16	0.255	-0.072	0.000	34	-0.036	-0.383	0.041	XXXX	XXXX	XXXX	
17	0.256	-0.082	0.000	33	-0.036	-0.392	0.032	XXXX	XXXX	XXXX	
18	0.257	-0.090	0.000	32	-0.036	-0.399	0.025	XXXX	XXXX	XXXX	
19	0.259	-0.097	0.000	31	-0.035	-0.404	0.019	XXXX	XXXX	XXXX	
20	0.261	-0.102	0.000	30	-0.034	-0.408	0.013	XXXX	XXXX	XXXX	
21	0.263	-0.106	0.000	29	-0.033	-0.411	0.009	XXXX	XXXX	XXXX	
22	0.266	-0.108	0.000	28	-0.031	-0.412	0.005	XXXX	XXXX	XXXX	
23	0.270	-0.108	0.000	27	-0.028	-0.411	0.003	XXXX	XXXX	XXXX	
24	0.274	-0.107	0.000	26	-0.025	-0.409	0.001	XXXX	XXXX	XXXX	
25	0.278	-0.105	0.000	25	-0.022	-0.405	0.000	XXXX	XXXX	XXXX	
26	0.283	-0.101	0.001	24	-0.018	-0.399	0.000	XXXX	XXXX	XXXX	
27	0.288	-0.095	0.003	23	-0.014	-0.392	0.000	XXXX	XXXX	XXXX	
28	0.293	-0.088	0.005	22	-0.010	-0.384	0.000	XXXX	XXXX	XXXX	
29	0.299	-0.079	0.009	21	-0.005	-0.374	0.000	XXXX	XXXX	XXXX	XXXX
30	0.306	-0.068	0.013	20	0.001	-0.362	0.000	XXXX	XXXX	XXXX	XXXX
31	0.313	-0.056	0.019	19	0.007	-0.349	0.000	XXXX	XXXX	XXXX	XXXX
32	0.320	-0.043	0.025	18	0.013	-0.334	0.000	XXXX	XXXX	XXXX	XXXX
33	0.328	-0.028	0.032	17	0.020	-0.318	0.000	XXXX	XXXX	XXXX	XXXX
34	0.336	-0.011	0.041	16	0.027	-0.300	0.000	XXXX	XXXX	XXXX	XXXX
35	0.345	0.007	0.050	15	0.034	-0.280	0.000	XXXX	XXXX	XXXX	XXXX
36	0.354	0.027	0.060	14	0.042	-0.259	0.000		XXXX		XXXX
37	0.363	0.049	0.071	13	0.051	-0.237	0.000		XXXX		XXXX
38	0.373	0.072	0.083	12	0.060	-0.213	0.000		XXXX		XXXX
39	0.384	0.096	0.096	11	0.069	-0.187	0.000		XXXX		XXXX
40	0.395	0.122	0.110	10	0.079	-0.159	0.000		XXXX		XXXX
41	0.406	0.150	0.125	9	0.089	-0.131	0.000		XXXX		XXXX
42	0.417	0.179	0.141	8	0.099	-0.100	0.000		XXXX		XXXX
43	0.430	0.210	0.157	7	0.111	-0.068	0.000		XXXX		XXXX
44	0.442	0.243	0.175	6	0.122	-0.034	0.000		XXXX		XXXX
45	0.455	0.276	0.194	5	0.134	0.001	0.000		XXXX		XXXX
46	0.468	0.312	0.213	4	0.146	0.037	0.000		XXXX		XXXX
47	0.482	0.349	0.234	3	0.159	0.076	0.000		XXXX		XXXX
48	0.497	0.388	0.255	2	0.172	0.116	0.000		XXXX		XXXX
49	0.511	0.428	0.277	1	0.186	0.157	0.000		XXXX		XXXX
50	0.526	0.470	0.301	0	0.200	0.200	0.000		XXXX		XXXX
51	0.542	0.513	0.325	-1					====		====
52	0.558	0.558	0.350	-2					====		====

Length of Overlap (+ve Wind Direction)

Length of Overlap (-ve Wind Direction)

Figure 389 - Sample of Overlap spreadsheet output

FIXED-ANCHORED OVERLAPS

With the help of the *Overlap* spreadsheet program, the design for an overlap, where both runs of wires are regulated, is relatively straightforward.

However, if one or both runs into the overlap are fixed-anchored, this brings in a whole new level of complications that need to be tackled in other ways. This is because the tension in the various wires change with temperature. So, the low tension (hot temperature), normal tension (21°C) and high tension (cold temperature) situations should somehow be modelled, and this is for both the contact wire and for its supporting catenary wire – both of which having vastly differing temperature/tension behaviours. And it may be that the 2 overlapping wire runs have different wire sizes and tensions from each other.

The ultimate aim is to provide a smooth pantograph transition from one contact wire run to the next, so the tension extremes need to be checked out for suitability.

For instance, the various overlaps for the fixed-anchored OHW inside the Airport Tunnels were initially modelled using the old-fashioned approach using sets of plastic temperature/tension curves, with different curve shapes for the different *T/w* values of contact and of catenary – at 10°C, 25°C and 55°C (or whatever maximum temperature existed for a particular run inside the tunnel). That's a lot of curves, all drawn at 1:50 vertically and 1:500 horizontally.

However, the beauty of using the plastic curves is that you can move them horizontally around and more readily understand the nature of what's trying to be achieved, especially with so many variables involved. My experience is that it's a bit more difficult to do this using CAD, unless a program has been written to solve overlap situations specifically (which it hadn't at the time). However, the final overlap designs for each situation in the Airport Tunnel project were documented in CAD.

The nature of the fixed-anchored wire means that the contact wire in the overlap bay has to be *droppered* all the way through the overlap bay, because of what might happen otherwise when an unsupported contact wire gets hot.

Fortunately, there are no significant cross winds inside the tunnel, so blowout didn't need to be checked out.

For more information on fixed-anchored overlaps, refer to *Section 4.1.1*, *Overlaps*.

OVERLAPS IN TUNNELS

In the open route, the design for the establishment of overlaps is fairly straightforward. The main advantage is that there are usually no space restrictions above the track that may otherwise limit the placement of catenary support fittings and anchors, at their "ideal" locations to set the relevant design staggers and heights.

It's a totally different matter for overlaps located inside tunnels. This is because the placement of catenary wires at their support locations and anchoring wires are all a function of the available (limited) headroom and the shape (e.g. curvature) of the tunnel in this often restrictive & awkward area.

It becomes a 3-dimensional puzzle, because the tunnel lining necessarily limits the placement of fittings, which often dictates catenary and anchor heights relative to track. (In tight tunnels, at any support location, if you want a certain stagger then you most likely need to accept a certain catenary height, and vice versa – although normally the prime outcome is to achieve a particular contact stagger and contact height at each location.)

For more information on this aspect, see *Section 4.1.5* which explains some of the difficulties encountered in the design of overlaps in the Airport Tunnel, along with design diagrams (wire profiles and S&R cross-sections) that help illustrate the nature of the problem.

NON-SECTIONABLE OR SECTIONABLE OVERLAP?

These days, there is minimal added cost of installing a sectionable overlap over a non-sectionable overlap (i.e. pennant insulators installed in out-of-running catenary and contact wires, and potential jumpers are probably the only extras).

So, when designing for new overlaps in a project, if there is any uncertainty whether there could be a benefit in future for isolating a particular overlap, then it may be prudent to design the overlap to be *sectionable*. Then there's a choice.

But if a *sectionable* overlap, at a particular location, is totally inappropriate for electrical sectioning – ever – then designing and installing it as *non-sectionable* prevents any such future sectioning (even if inadvertent), and this approach may have merit.

CLEARANCE BETWEEN SWUNG CANTILEVERS

In the open route, a normal overlap has a pair of masts at both ends of the overlap bay, and each of these pair of masts are typically spaced 2m apart.

This 2m spacing gives plenty of mechanical clearance when the cantilevers swing under temperature extremes, as shown in *Figure 390 (a)*. This diagram assumes a maximum tension length of about 1,000m for each wire run, and with "M"oving tension regulators (weight stacks) installed at both associated anchors at the ends of this overlap.

This 1,000m of wire, under hot and cold conditions, results in longitudinal cantilever swings of about ±500mm about their design position (normal to the track). So, in the cold (blue) case the clearance between swung cantilevers reduces to about 1 metre.

Sometimes this 2m mast spacing is reduced to 1m, as would be the case if a twin drop vertical is used instead (from a portal structure). This situation is depicted in *Figure 390 (b)*.

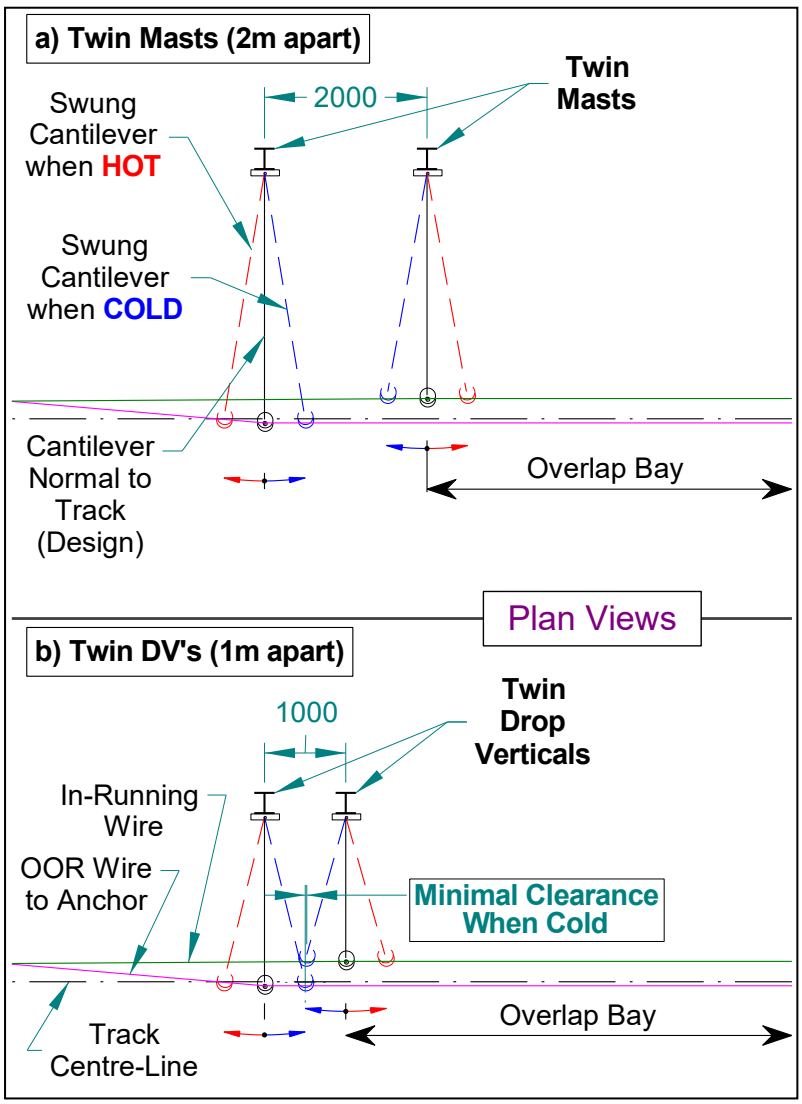


Figure 390 - Space between swung Cantilevers

Here, the cantilever swing with this reduced 1m separation, will need to be checked out in cases of extreme wire run lengths, to ensure the cantilevers won't clash. Refer to "Minimal Clearance When Cold" caption in lower diagram. And it should be checked periodically for appropriate clearances throughout its service life, as wires permanently stretch or otherwise move longitudinally.

There have been some cases from Waterfall to Pt Kembla where twin portals were installed on common concrete foundations in overlaps, and these were spaced at 1.5m apart (as I recall). This situation gives extra clearance between swung cantilevers when compared to the 1m spacing of twin drop verticals, which is good. But it was also very unlikely that the full 1,000m tension lengths were ever encountered here because of the extremely winding track – necessitating much reduced tension lengths – for much of the route.

It might be fortunate that, if there's any wire stretch in time, this is likely to improve clearances between cantilevers. But if that stretch is over-corrected, then these cantilever clearances should again be checked out.

3.5.0.6 Status (c. 2014)

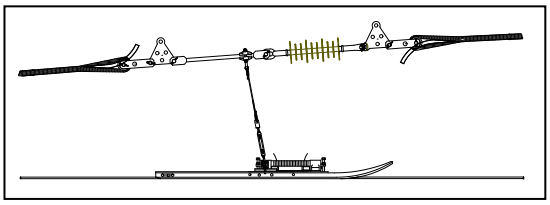
The *Short Bay Overlap* arrangement is preferred, due mainly to its more compact configuration over 3 bays. (It can be installed in many more track situations due to its ability to use shorter bays.)

3.5.0.7 Reference

Refer to *Table 33* for typical examples of overlap drawings.

For more information on Overlaps refer to my document "Fundamentals of OHW Overlap Design", dated 12/11/2002 (although Standards may have changed things over time).

3.6 SECTION INSULATORS



3.6.0 General

3.6.0.1 Description

A "section insulator" (SI) is a piece of equipment that can be installed in line with the contact wire at just about any location within a bay. It includes lateral runners on each side of the contact wire, and an insulator for electrical sectioning of the wire run at that point.

The SI includes catenary insulation and support wires located above the body of the SI.

3.6.0.2 Function

A section insulator provides the following functions:

- It provides appropriate insulation for forming 2 independent electrical sections at a nominated location within a wire run.
- It allows a continuous and smooth mechanical path for pantographs to slide under.
- It is configured for allowing uninterrupted electrical supply to the pantograph as it passes from one electrical section to the next. (In doing so, the pantograph temporarily bridges out both electrical sections.)

Section insulators perform many of the functions of overlaps, however, they hold the following advantages:

- SIs are more compact (between 1.5m and 3.3m long) and can be installed at almost any point in an OHW bay. (See *Figure 404* and *Figure 405* further on for typical dimensions.)
- They are cheaper to install than establishing an overlap, and require less time to install.

Their main disadvantage is their increased maintenance effort. If the SI is not correctly set up, the alignment and condition of side runners can quickly deteriorate, particularly with high speed pantograph traffic.

3.6.0.3 Typical Components

Referring to *Figure 391*, the following main components of the ***SI Body*** and the ***SI Support*** are common to most section insulator arrangements.

SI BODY

This is the lower portion that interfaces with the train pantographs. It includes:

- *Clamps* for terminating the contact wire (or wires if twin contact) under their full tension,
- *Insulators*. The insulators must provide the necessary electrical isolation (1500V), and be strong enough to handle the various mechanical loads applied to it, including:
  - *Tension.* The full conductor tension is applied.
  - *Bending.* The height difference between the centroids of insulators and of the contact wire, under extreme tension, causes a considerable bending moment on the insulators. And the uplift force of passing pantographs tends to bend the SI upwards at the insulator.
  - *Torsion.* This depends on the amount of "twist" in the contact wire, etc.
- Copper "*Runners*". These are installed on each side of the SI at contact wire level, and they provide the necessary smooth mechanical and electrical path for the pantograph to

slide under the SI body. This includes the necessary adjustment provision for proper alignment of the runners.

- "*Arcing horns*" (if installed) are used to help extinguish any arc that may be established if significant current is drawn as each pantograph passes through from one electrical section to the next.
- The SI "*frame*". This is the main part of the body that allows the attachment of all the various components listed above. Items can be fastened or held in place using:
  - Set screws, bolts & nuts,
  - Pin connections (e.g. joining the contact terminating clamps to the body),
  - Copper rivets (to runners).

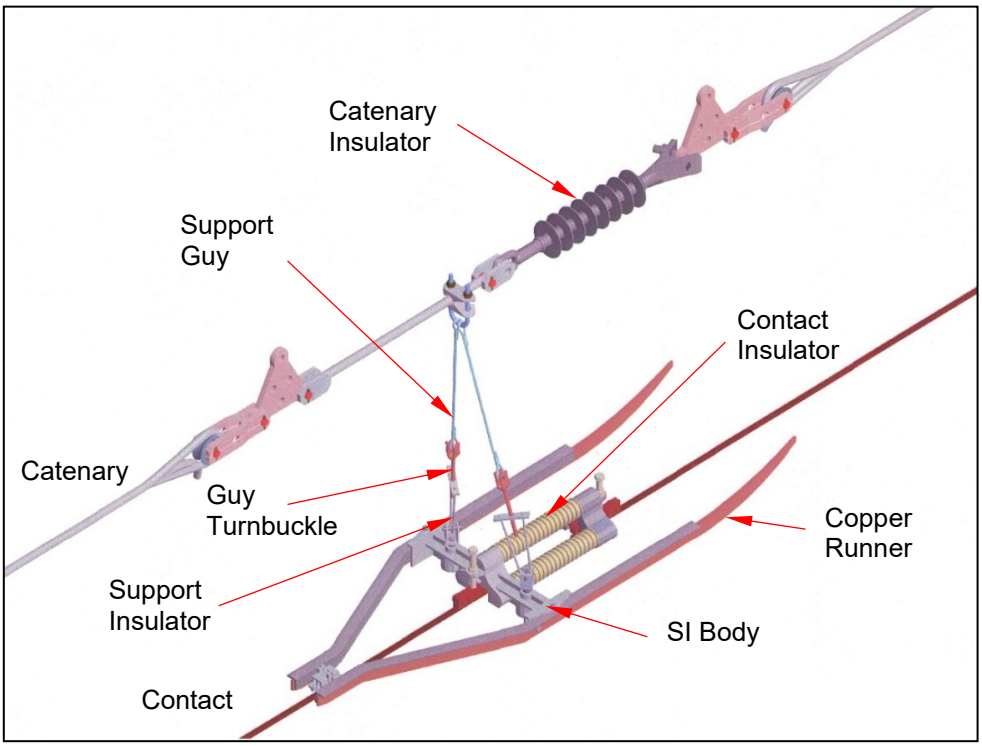


Figure 391 - Section Insulator components

SI SUPPORT

The weight of the section insulator is normally supported from the catenary wire, which can also allow the SI to have the proper profile alignment for good pantograph interface performance. It includes:

- The *catenary insulator*. This is for providing electrical isolation between the 2 electrical sections.
- *Support guys*. Stranded support wire (often stainless steel or copper) is used for supporting the weight of the SI from the catenary wire. The guys may include some insulation to prevent small currents passing from catenary to contact through guy wire supports and the SI body. (This low-level insulation is particularly important if using stainless steel wire.)
- *Turnbuckles or other hardware* for providing fine *lateral* and *longitudinal* adjustments, to set the level of the copper runners correctly for proper pantograph running (which is especially important at higher speeds).

3.6.0.4 Configuration

Throughout Sydney's electrified system, there are 3 major types of section insulators:

- Type 5 SI. I understand this was developed by the NSW Railways (1950s).
- Type 6 SI. This SI is manufactures in France by Jacques Galland.
- BICC (Compound System) SI. I think this may have been an adaptation of the Type 5 SI, to terminate a 3rd wire – the auxiliary catenary wire – located between contact and catenary wires.

If you dig through the historical design drawings you may come across the predecessors to the Type 5 SI, i.e. Types 1, 2, 3 & 4. None of these are considered important enough to include in this document.

A new type of section insulator is also currently on trial, mainly to alleviate some problems with existing SIs and to provide alternatives in case problems arise in future.

Various height adjustments are normally provided on the SI, which allow it to be properly aligned with respect to the pantograph. Correct alignment is essential in both the along-track and cross-track directions of the SI body and runners.

Section insulators are usually configured to allow for electrical sectioning, otherwise there's no point in having them installed. (Note that some SIs may have been subsequently "bridged out" to provide electrical continuity but without the need to remove the SI itself. This was most probably done to readily allow for some future isolation if needed at that point.)

Section insulators installed in regulated OHW give the best dynamic performance, as the conductor tensions and sags do not vary with temperature, so the alignment of the SI remains intact regardless of temperature.

This is not so with the fixed-anchored OHW, where the tensions (and particularly the contact tension) changes dramatically with temperature. This complication essentially means they should not be installed in main line situations with high speed trains. And if installed, it may also necessitate reduced speeds especially in the summer when the tensions are at their lowest.

TMP Code	Equipment Name	Made By	Drawing No.
EP-08-31-00-00	**Section Insulator Arrangements**		
EP-08-31-01-00	*(Type 1 S.I)*	*RailCorp*	
EP-08-31-06-00	*(Type 2 SI)*	*RailCorp*	
EP-08-31-11-00	*(Type 3 SI)*	*RailCorp*	
EP-08-31-16-00	*(Type 4 SI)*	*RailCorp*	
EP-08-31-21-00	*Type 5 SI*	*RailCorp*	*B/72754*
EP-08-31-31-00	*Type 6 SI*	*Jacques Galland*	*EL0166884 & EL0030508*
EP-08-31-36-00	*BICC (Compound) SI*	*BICC ?*	*C/74700*
EP-08-31-41-00	*Traverser SI*	*RailCorp*	

Table 34 - Section Insulator arrangements

As of 2012, the following population of section insulators exists in the 4 Districts.

District	Approx. No. of Section Insulators*			
	Type 5	Type 6	Compound (BICC)s	Total
North	100	128	0	**228**
Central	173	327	0	**500**
West	113	100	19	**232**
Illawarra	33	135	0	**168**
Total	**419**	**690**	**19**	**1,128**

* As at beginning of 2012 – obtained from RailCorp Asset Explorer.

Table 35 - Section Insulator population by District (c. 2012)

3.6.0.5 Design Notes

INSULATION

Even though the SI has 1500V insulation in line with both the contact and catenary wires, for the majority of time (in normal situations) these insulators are not electrically stressed at all – they have +1500V on each end, so the voltage across the insulators is close to 0V.

It's only when the OHW on one side of the SI is electrically isolated & rail-connected that the insulators need to work hard, with the full 1500V potential applied across them (and also making them more susceptible to lightning flashover during storms).

COMPLIANCE

It's unfortunate that the extra weight of the SI, compared to the weight of a contact wire, has to affect the running performance of a pantograph when passing under the SI. To a degree, this can't be avoided.

Ideally through a bay, the pantograph should see the same downward pressure (weight of contact wire) acting against its own upward pressure – the term used is *compliance*.

When the pantograph at speed comes under an SI, the sudden "hard spot" of the SI weight can cause a mechanical disturbance and may result in some arcing, and will likely also generate vibrations or oscillations in the contact wire that the following pantographs of the same train then have to negotiate (with each possibly compounding the extent of contact wire / SI movement)!

So, the lighter the SI body, the better the outcome in this regard. (Correct alignment of the SI is also imperative.) For more on *compliance* see *Section 3.2.0.5, Compliance*.

GUY ARRANGEMENT

The guy arrangement from the catenary wire to the SI body generally does 2 things:

- It helps support the weight of the SI body and fittings, and
- It controls the alignment of the runners, which promotes good pantograph interface (especially at speed).

My understanding is that, for best alignment stability, the guys should be installed ***close to vertical*** (in the longitudinal direction).

Unfortunately, there are many instances in the field where the guys have been installed almost horizontally (especially for Type 5 SIs). While this might look OK (?), this makes the SI runners susceptible to going out of alignment laterally if the catenary moves even a small amount longitudinally relative to the contact wire below it. (Refer for example to *Note 6* on Type 6 SI drawing EL0030508.) It's fairly common to see loose guy wires in the field.

Of course, sometimes a shallow guy wire angle is all that can be achieved. There are at least 2 things that can cause a shallow angle:

- *Shallow system depth*. If long turnbuckles are installed in the guy wires (for adjustability), then their length may lead to a fairly long guy wire arrangement, which can only fit if the guys are connected to the catenary further (longitudinally) away from the SI body, and this leads to a shallow angle. This applies if the system depth is typically 300 to 500mm.
- *Length of catenary insulator/s*. Ideally this insulator should be installed vertically in line with the insulators on the SI body. However, the sheer length of some catenary insulator arrangements (including terminating hardware) can prevent the guy wire attachment to bare catenary from being installed directly above the section insulator. (This is particularly true if the catenary is terminated using long wrap-on fittings which can't have anything clamped onto them, per *Figure 140*.)
  See *Figure 395* further on for example, which also has a shallow system depth.

There are many examples in the field where there is no reason why the catenary attachment clamps could not be located closer to the catenary insulator, to give a more vertical guy angle, which would be a desirable outcome – see *Figure 397* further on for example. (Note that the standard arrangement drawing shows the guys with quite a shallow angle, but maybe this is because the length of the catenary insulator hardware prevents a more vertical guy arrangement being designed in this case.)

SHORTING DISTANCE

In order to provide a smooth mechanical path under the SI, and to minimise the chance of electrical disruption to the train, the SI is designed so that a pantograph will momentarily short-out the 2 electrical sections. This happens as the pantograph's carbon strip pairs bridge from the contact wire or runner/s of one electrical section over to the copper runner/s connected to the next electrical section.

The *shorting distance* is the distance that a travelling pantograph effectively bridges out the 2 electrical sections. It comprises the overlap distance provided by the SI runners, *plus* the shorting distance of each pantograph (= the width of the carbon strips *plus* the spacing between the pairs of carbon strips on each pantograph, which are shorted out to each other on the pantograph head).

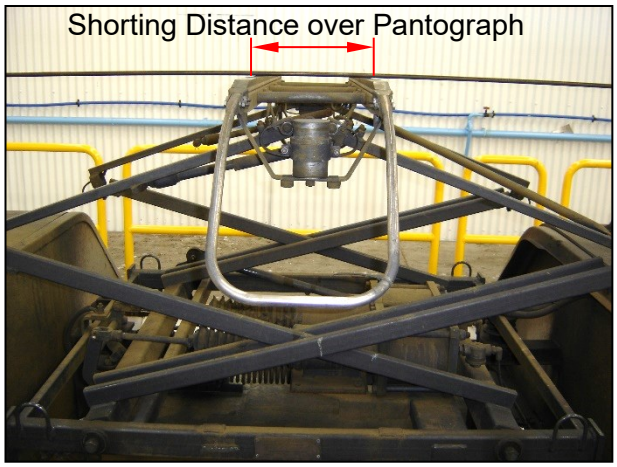


Figure 392 - Pantograph carbon strip spacing

Figure 392 shows the typical distance between front of leading carbon strip to end of trailing strip. See also *Figure 690* much later on, which shows the typical width and relative distance between carbon strip pairs (for a Type 6 SI situation).

ARCING HORNS

Arcing horns are intended to quickly extinguish any arc that may result as a pantograph passes through a section insulator *whilst drawing current*.

Arcing horns are set up by forming or installing a metal rod to each electrical section in the immediate vicinity of where an arc can establish. They are normally shaped like a "V". This shape helps by lengthen the horizontal *arc distance* as the arc travels up the "V" (assisted by its own convective heating), to such an arc length that it is no longer sustainable, and so the arc extinguishes. It was mentioned in *Section 2.6* that an arc is unlikely to be sustained with 150mm gap, and the top of the "V" is greater than this distance.

The arc extinguishing takes place in less than 1 second – this is important as any longer duration would lead to substantial damage to the arcing horns and possibly even to the surrounding equipment. The arc contains a huge amount of energy in the form of heat. If the arc passes enough current, it can also melt parts of the arcing horn metal and spatter this molten metal elsewhere nearby, and any damage can accumulate over time. See *Figure 406* further on for an example of the consequences of arcing "spatter" on the underside of an SI.

The early SIs had arcing horns made simply by turning up the ends of each copper side runner – very cheap, but effective. The only problem is that, at the low end where the runners bent upwards and back by about 120°, the deformation in this bent area made it susceptible to fatigue as well as excessive wear as pantographs often struck the lower end of this bend.

It's interesting to note that the Type 6 section insulator (described later) will always generate an arc if a pantograph powers through the SI in its "reverse" direction, and so arcing horns are mandatory in this situation. However, there is no need for them if the trains always travel in the "forward" direction – any arcing is quickly extinguished by both side runners which bow upward at the trailing end of the SI. This is described further in *Section 3.6.2.5*, *Normal Running Direction*.

DAMAGE DUE TO PANTOGRAPH BRIDGING SI

Section insulators are not designed for the situation where a pantograph can *stop* directly under and electrically short out the 2 electrical sections. Were this to happen, then current could pass from one electrical section through the pantograph to the next section. When heavy current is drawn through the resistive connections involved – copper to carbon then carbon to copper – it could lead to localised overheating of the copper (contact wire) and carbon (pantograph) interface. This in turn could:

- Cause the contact wire to overheat to annealing point, then stretch under tension and snap.
- Lead to localised arcing, which may melt the contact wire or runner and destroy it locally.

There have been many instances at various places over the years where a pantograph has parked under an SI and resulted in broken contact wire. The consequent repair can take quite a long time to fix and cause much disruption to services.

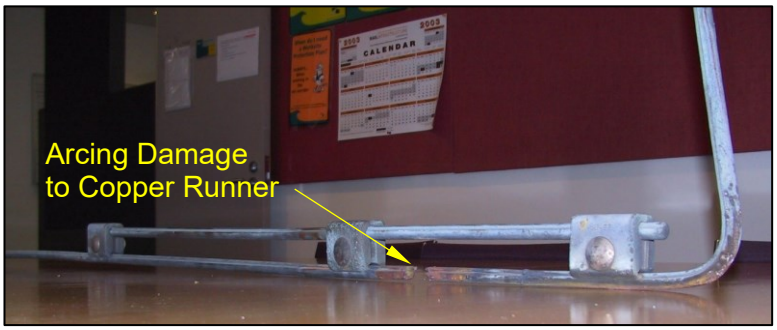


Figure 393 - Arcing damage to Type 5 SI Runner (Illawarra Dive, 2003)

Refer to *Figure 393*, which shows a missing section of contact wire (side runner from a Type 5 SI) that had melted due to prolonged arcing. This damage may not always happen, as it depends on the amount of current needing to flow from one section to the next (which can depend on the density of nearby traffic demanding current).

Note that there are situations around the network where this scenario cannot be avoided.

Indeed, there are situations where an "open overlap" was replaced by a section insulator, simply to significantly reduce the risk of a pantograph parking under it, in a position that

bridges out the electrical sections, and the possible consequence of the OHW burning down. The length of "overlap" between electrical sections is of the order of 2m to 20m for an overlap, whereas a section insulator can reduce this to the order of 100mm or so, which is a huge (at least 10 fold) improvement in terms of risk exposure. But there is always some risk even with an SI.

Figure 394 gives an idea of the amount of damage that can result from parking a pantograph under a Type 6 SI and bridging out the 2 electrical sections (I've added a red line to show where the contact wire would have been, and blue lines for the carbon strips of the stationary pantograph).

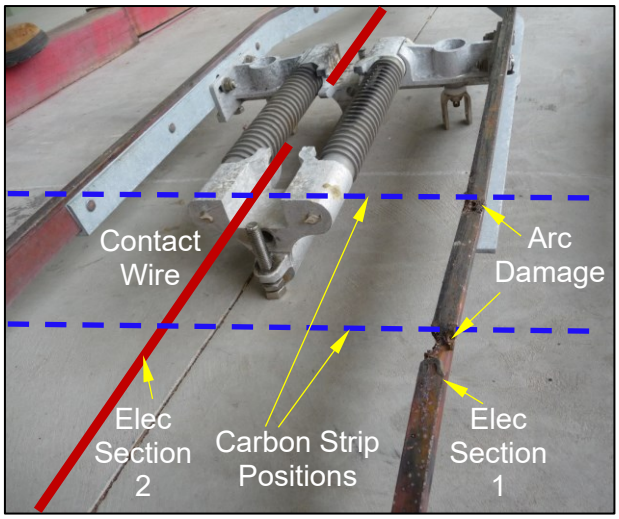


Figure 394 - Under-side of Type 6 SI showing damaged runner

In this situation, a light contact from stationary carbon strips to one of the side runners would have been sufficient to cause arcing to start at the 2 locations shown, melting parts of the copper runner in the process and developing a larger gap for more significant arcing to do further damage. (The voltage across the arc is only a few volts, which could be driven by the current flow from 2 totally different electrical sources or from different resistive paths back to the substation.)

Note that the main contact wire would have been unaffected, as was the opposite runner. It's also fortunate that there's no tension in the side runners here – they support their own weight. So, arcing damage may not stop trains (but the damage would need to be identified and fixed).

Had the roles been reversed, with the small gap appearing under the contact wire and with the carbon strips in good contact with the side runner, the contact wire would have arced and this would more likely have caused it to snap and bring down the contact wire – stopping this and other trains.

None of the above 2 examples of bridged SIs is intended to criticise the SI involved – the problem has to do with the *bridging situation*. No matter what form of SI (or overlap) is involved, the outcome will likely be the same – OHW damaged and trains stopped until it's repaired! The relative "Overlap Lengths" between the Type 5 and Type 6 SIs are given in *Figure 405*. This problem involves *probabilities* – of various aspects happening at the same time.

For more on this situation, refer to:

- *Section 5.5.3.5*, *Pantograph Bridging an "Open" Section Insulator*.
- *Section 6.5.1*, *Relative Positions of Signals & Open Overlaps*.

JUMPERING AN SI

The purpose of a section insulator is to allow the convenient electrical sectioning of an in-running contact wire, just about anywhere in the wire run.

If, for whatever reason, the electrical sections need to be reconnected, then this can be achieved by installing a "catenary jumper" across the catenary insulator associated with the SI, thus bridging it out.

This jumper needs to make good electrical connection to the catenary wires being joined, ideally to the tails of the catenary (under no tension). It involves installing multiple parallel clamps to the cleaned catenary wire. If the clamps are installed on the tensioned catenary

wire and the connection is not properly cleaned and clamped with a tight tension, then any resistive joints, when passing heavy current, can cause the catenary wire to heat up, anneal and stretch under tension and ultimately snap!

These days, the jumper arrangement should also include in-span feeder wires connecting from the untensioned catenary jumper down to all contact wires involved.

The jumpering can, of course, be disconnected if required. But if this connecting and reconnecting needs to be done at various times, it may be prudent to install a switch across the SI instead, for added convenience (and to keep workers away from the running tracks).

OTHER SIS

Since the 1970s several other section insulators from overseas were considered for use in Sydney's OHW system. And some were trialled, but most seemed just too lightweight and flimsy to be suitable for Sydney's heavy OHW system at the time.

I believe part of the problem lay with the heavy nature of the OHW equipment – its big conductors and associated fittings, and ultimately its behaviour (notably the fixed-anchored temperature/tension character). But the other significant contributor was the heavy nature of the pantographs used back then. And probably all this was tied in with the large amount of current to be delivered to the freight trains (with all pantographs raised) at the time.

Lightweight overseas SIs were simply not able to cope with the treatment dished out by the pantographs reacting with the heavy OHW system *at the time*.

However, I think things seemed to change when lighter single-arm pantographs were introduced and became standard in Sydney's network.

This aspect is discussed further on in *Section 6.3.2.7*, *Section Insulator Strengthening*.

3.6.0.6 Status (c. 2014)

- *Type 5 SI* – Sydney no longer installs Type 5 SIs. This is partly because the insulating beam (Permali) can no longer be source. Use Type 6 SI instead.
- *Type 6 SI* – To be used in all future works.
- *BICC section insulator* – This is built specifically for the compound OHW system (Emu Plains to Bowenfels OHW). A modified Type 6 SI arrangement has been developed as a substitute for the Compound SI, although its application in each instance needs to be checked out by Design.
- *Other SIs* ? – refer to Electrical Standards.

At the time of writing, a new section insulator was under trial, and it may already be accepted for use in Sydney's system. So need to check the current standards for details of its acceptance and usage.

3.6.0.7 Reference

See *Table 34* for drawing references.

3.6.1 Type 5 Section Insulator

3.6.1.1 Description

The evolution of various types of SIs through the years by the NSW Railways has apparently led to the development of the Type 5 Section Insulator. Its standard arrangement drawing was signed off in the 1950s.

This SI has been used extensively throughout the network into the 2000s, but is now no longer installed in new OHW. An instance of this SI is given in *Figure 395*.

3.6.1.2 Function

See *Section 3.6.0.2*.

3.6.1.3 Typical Components

Even though this is a relatively old design, the Type 5 SI looks remarkably similar to other current commercially-available section insulators, so obviously the formula was right even back in the 1950s when it was developed and signed off by the NSW Railways. (The predecessors to this SI were likely influenced by overseas designs at that early time.) Refer to *Figure 396* which shows a copy of the old design drawing.

This section insulator is symmetrical, so there is no preferred pantograph running direction (unlike the Type 6 SI) – see *Figure 395*.

The most important components are:

- *Contact terminating clamps* (fitting 511/19). These are the standard contact half-splice fittings that are also used in other contact termination situations in the network. See *Section 3.1.6* and *Figure 122* for more information.
- *Permali beam insulators* (fitting 511/33). These are cross-laminated timber beams that are particularly strong in tension ("timber" you say?). These days they are normally painted white. (This may have been be to show they've been reconditioned due to the scarcity of this material? Or to help protect them from the damaging effects of UV sunlight.) Two are used side by side with a small gap in between them. Apart from adding strength, this configuration and spacing gives the arrangement some rigidity at the contact level (as uplifting pantographs pass by).
- *Copper runners* – "long runners" and "short runners" (fittings 511/28 & 29). These are lengths of straightened 137mm² contact wire, which are bent at both ends – one end has the classic "arcing horn" shape, and the other end is bent slightly upwards to promote a good lead-in to the SI and to prevent snagging a pantograph. On each side of the SI there are the 2 lengths in series with a gap in between them – on one side there's a short and then a long runner and on the other side there's a long and then a short runner. The spacing between the different length runners provides an "air gap", which is offset on each side of the SI. This longitudinal offset of gaps is primarily for providing a mechanically continuous path for the pantograph (otherwise the pantograph would rub against the underside of the permali beam insulators). The gap also helps prevent supply interruption as the pantograph runs through. The offset gaps can be seen in the top view of *Figure 396*. However, these offset gaps also lengthen the "shorting distance" when a pantograph (with its twin carbon strips) passes through.
- *Runner stiffeners*. Short lengths of stiff contact wire are clamped above each of the side runners, to help provide these runners with some significant stiffness to counter the effects of each passing (uplifting) pantograph. This is especially needed in the crucial area near where the runners are bent upwards forming arcing horns.

- *Contact attachment clamps*. These various clamps attach the side runners to the contact wire. They also attach runner stiffeners to the runners.
- *Guy arrangement*. The 4 guys help support the weight of the SI from the catenary wire. (Some of the weight of the SI body is also taken by the highly tensioned contact wire and adjacent droppers, also up to the catenary wire.) In addition, and importantly, the guys also provide lateral alignment adjustment for achieving flat runners (the runners should be parallel to the superelevated rails of the track). Unfortunately, the shallow angle of guy wires from SI body to the catenary can sometimes lead to the SI going out of alignment, especially if the catenary drifts in one direction or other (relative to the contact wire) for whatever reason. As argued in *Section 3.6.0.5*, *Guy Arrangement*, the guys provide the most stability when their angle is vertical, if that can be achieved (but this can be limited by the length and position of the catenary insulation equipment, as shown in the elevation view of *Figure 396*).
- *Catenary insulators*. Initially a pair of large *loop strain* porcelain insulators were used. Then came the 250mm diameter termination insulator (fitting 453/12) generally used in pairs, and more recently the fibreglass K-Line insulator (fitting 453/16) were adopted.

Figure 395 - Type 5 Section Insulator

Figure 395 shows the use of a pair of porcelain loop strain insulators which were likely relatively cheap and available in the old days. They are not really suited to high voltage use because there's no way to "shed" water to prevent it streaming when it rains heavily (which might lead to flashover). However, for a fairly low voltage 1500V system, and because there are 2 used in series and located well apart (to improve flashover performance), they must have proven quite effective in the past.

The other thing that may have allowed this configuration is the fact that, for probably 99.9% of the time, the voltage on both sides of the insulator group is the same 1500V potential – the insulators are only ever stressed at 1500V when one side is isolated from supply (and rail-connected). To my knowledge this configuration has never really had reliability issues.
The big advantage of using loop strain insulators is that the system depth (catenary to contact vertical distance) can be much smaller than if termination insulators were used (with their larger diameter porcelain sheds). *Figure 395* tends to show this, and also *Figure 399* (with a system depth so low as to require a shield).

Apparently the SIs weight is approximately 360N (80lb), according to an old drawing.

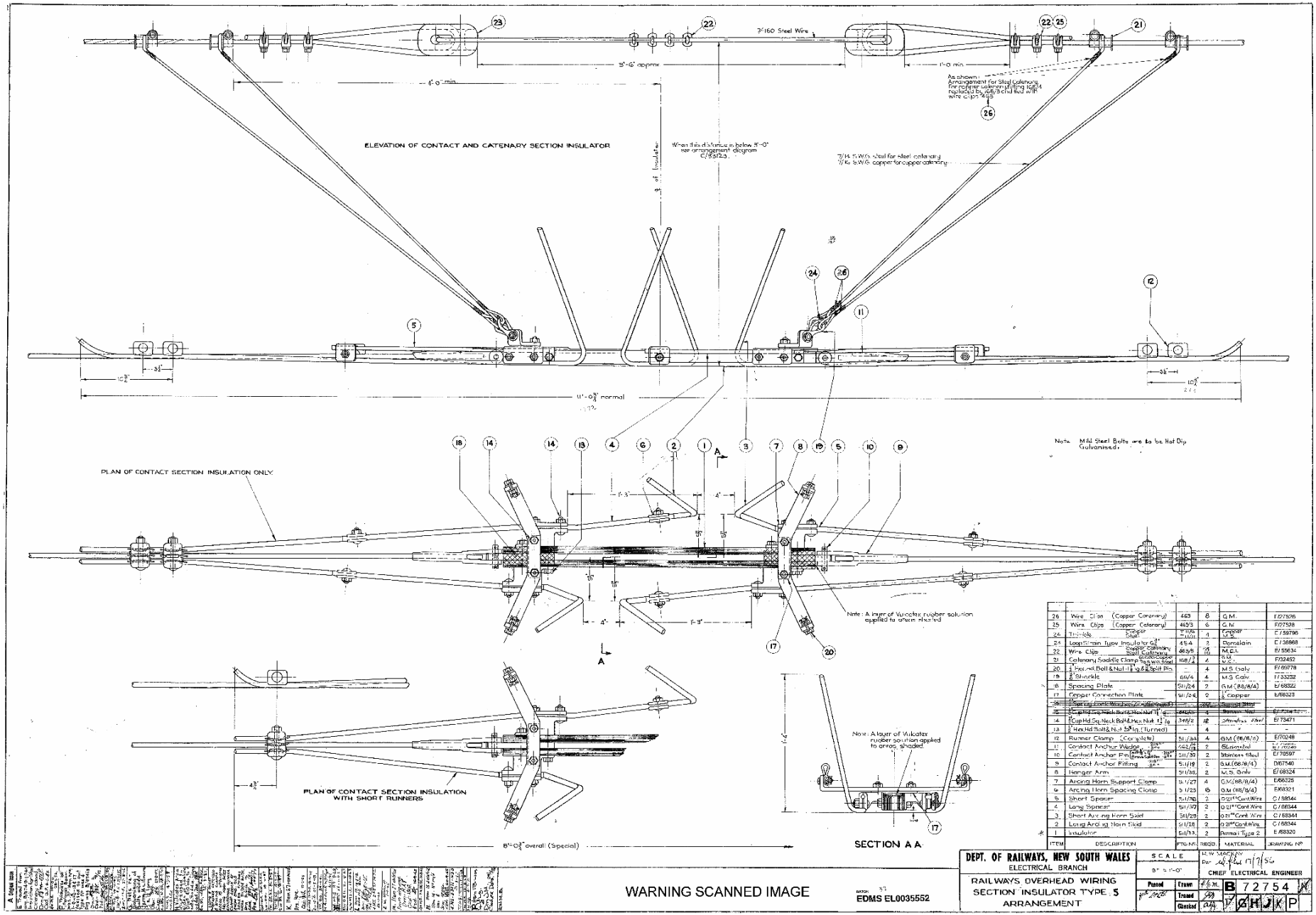

ELEVATION OF CONTACT AND CATENARY SECTION INSULATOR
PLAN OF CONTACT SECTION INSULATION ONLY
PLAN OF CONTACT SECTION INSULATION WITH SHORT RUNNERS
SECTION A A
7/160 Steel Wire
7/14 S.W.G. steel for steel catenary
7/14 S.W.G. copper for copper catenary
Note: Mild Steel Bolts are to be Hot Dip Galvanised.
Note: A layer of Vulcatex rubber solution applied to areas shaded
DEPT. OF RAILWAYS, NEW SOUTH WALES
ELECTRICAL BRANCH
RAILWAYS OVERHEAD WIRING SECTION INSULATOR TYPE 5 ARRANGEMENT
SCALE
CHIEF ELECTRICAL ENGINEER
B 72754
WARNING SCANNED IMAGE
EDMS EL0035552

Figure 396 - Type 5 Section Insulator – old drawing

3.6.1.4 Configuration

The Type 5 SI is designed for incorporation into OHW systems where track speeds do not exceed about 60 to80km/h. As such, they are mostly installed in crossovers and turnouts where traffic is relatively slow speed (typically less than about 40km/h).

Installation into a main line with high pantograph speeds can lead to significant damage to the SI over a short period of time. This is because the runners are configured to push the pantograph about 6mm (1/4") lower as it passes through – this is done to gain some vertical clearance to the "permali" insulator and contact half-splice end fittings, to prevent the pantograph from rubbing against these parts. At high speed, this lowering effect, although small, causes a significant mechanical disturbance to the OHW, generating vertical movement with consequent arcing and wear (and which subsequent pantographs of the same train need to then negotiate).

It is to be expected that these SIs perform better in regulated OHW than in fixed-anchored OHW, as a constant high tension can maintain better alignment of the SI.

The SI has 2 insulator beams in parallel. These beams share the full contact wire tension and provide the electrical sectioning requirement of the section insulator. The beams are made from *permali* which is a cross-laminated timber product. An end view of the permali beam shows that it has a concaved curve on the top (shown in *Figure 400*). This is to prevent rain water from pooling, which minimises any leakage currents across the insulator, and also lessens the chance of the timber beginning to rot and subsequent degradation in time. Permali is incredibly strong in tension (as required), but over time it has the tendency to carbonise on the underside (mostly due to the arcing taking place in the immediate area). This damaged area then tends to collect moisture, which leads to current leakage problems when the power is removed from one side. (Any small leakage current sometimes causes the voltage to show up as too high in the dead section when "testing dead", which creates concern when trying to apply rail-connecting equipment.) There have been attempts to change over to a pair of synthetic fibreglass rod insulators, but this was never a success because the fibreglass flexes way too much. See *Section 5.1.16.2, Permali Beam* for more details of this material.

The SI is supported by a pair of guy wires installed on both the approach and departure sides of the SI.

- Older designs had independent catenary saddle clamps for each guy wire connection to the catenary (*Figure 395*). This provided guy adjustment by sliding the clamps along the catenary to gain the appropriate tension in the guy wire and alignment of the SI. But it required that there be suitable space between the saddle clamps for such adjustment.
- A newer approach seems to be to use the locally manufactured stainless steel guy turnbuckle (the same as used on the Type 6 SI) installed on each guy wire and terminating on a catenary U-bolt clamp, as depicted in *Figure 397*. Interestingly, there doesn't appear to be any insulation in the guy wires to prevent low level current feeding through this wire – having stainless steel turnbuckles in the path should be a concern. (Note that this particular SI is connected to a switch through aerial feeder connections to the 2 tails of the catenary.)

Because of its symmetrical design, the Type 5 SI is suitable for bi-directional train operation, rated for the same speed.

This style of SI also has a relatively narrow lateral distance between side runners compared with the runners of the Type 6 SI. This can have significant advantages (especially if and when a bowed pantograph is ever accepted into Sydney's system – see *Section 6.3.2.1, A Proposed "Bowed" Pantograph Head*.

Figure 398 shows the vulnerable wear areas on the side runners, at the elbow bend that forms the arcing horn. If the SI is not installed parallel to an inclined (superelevated) track, this can cause the pantograph to strike one of the elbows and cause such wear. Also, if an SI is installed with some non-zero stagger relative to track, a worn pantograph (e.g. *Figure 63*) coming through can strike one of the elbows and cause it to wear over time. There are other mechanisms that can cause such wear over time.

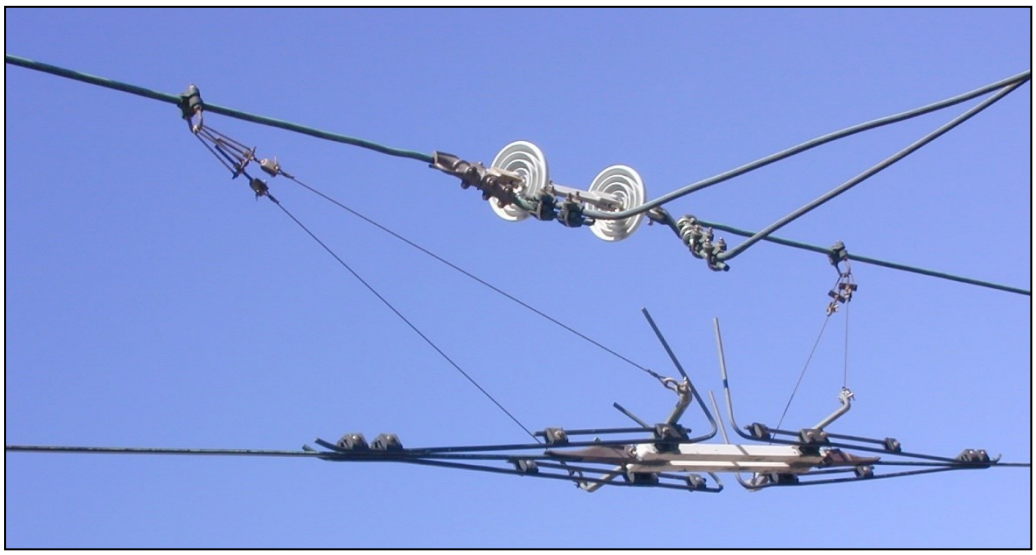


Figure 397 - A Type 5 Section Insulator with aerial feed (note the white beams)

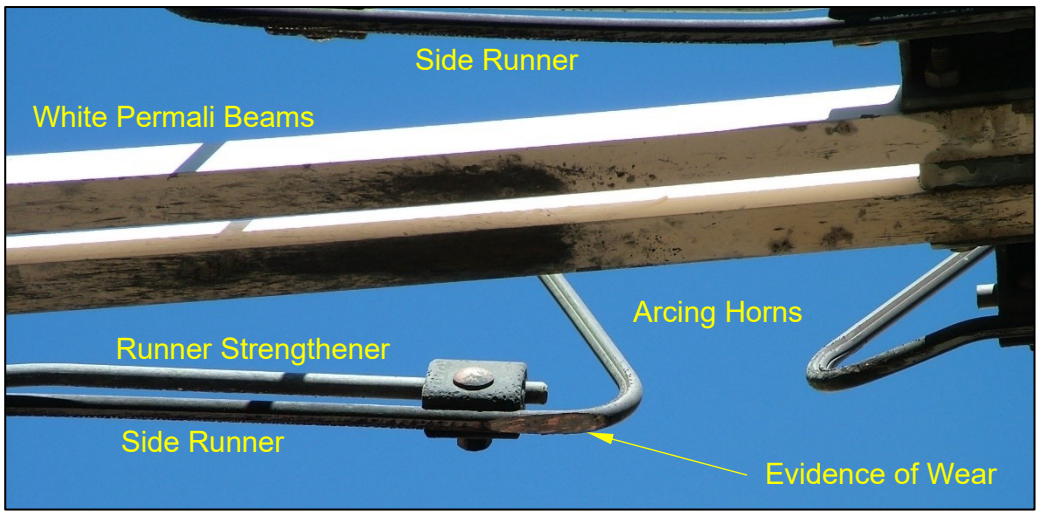


Figure 398 - Worn Runners at the Arcing Horn (underside of Type 5 SI)

3.6.1.5 Design Notes

SECTIONING DISTANCE

The distance between the side runners at the base of the arcing horns is about 102mm, as indicated in *Figure 405*.

SHORTING DISTANCE

When a pantograph passes under a Type 5 section insulator, each carbon strip on the pantograph will short out both electrical sections by a distance of about 180mm (plus the

width of each carbon strip and the distance between the pairs of carbon strips on a pantograph head).

This spacing of 180mm is shown further on in *Figure 405* (and compared with a Type 6 SI).

SPEED LIMITED

The side runners of the Type 5 SI ramp down to a slightly lower level than the entering and exiting contact wire (by about 6mm – refer to Section A-A on *Figure 395*). This is needed so as to prevent pantograph contact (and thus wear) with the underside of the permali insulating beams and connected half-splice clamps.

While this 6mm figure may sound trivial, unfortunately this does not result in the perfectly flat path that higher speed pantographs expect to see. As the side runners force a pantograph down by this amount, over a very short distance when passing under the SI, this creates a mechanical disturbance to the OHW, and the higher the pantograph speed the worse this disturbance gets (with accompanying arcing). The problem can become particularly bad of any following pantographs on the same train.

It is basically for this reason that the Type 5 SI is only suited to slow to medium speed traffic (maybe up to 80km/h in a regulated system, much less in a fixed-anchored system).

GUYS

Referring to *Figure 395*, the keen eye will see that in this instance it shows the 2 guy wires attached to the tensioned catenary wire on the left side, but on the right side the 2 guy wires are attached to the tail of the catenary.

It would seem that someone had decided to use a catenary *wrap-on* fitting on the right side to terminate the catenary wire. The use of a wrap-on prohibits the installation of any clamps onto any part of the wrap-on itself (otherwise the wrap-on's gripping mechanism may suffer, allowing the wrap-on strands to slip on the catenary wire!). So, because the wrap-on is quite long, no doubt the easiest thing to do was to clamp to the catenary tail, although connecting to the untensioned tail of the catenary is probably not the best outcome (?).

For best alignment and lateral stability, the guys should be installed close to vertical. However, there are many instances in the field where the guys are almost horizontal. While this might look sleek, unfortunately this makes the SI runners susceptible to going out of alignment if the catenary moves longitudinally relative to the contact wire below. In this case. one set of guy wires could become tight and the other become slack.

A look at the elevation view in standard arrangement drawing of *Figure 396* has the guy wire connections to catenary located very close to the catenary insulator arrangement which is quite long, but places the guys at about 45° to horizontal or steeper. To me, this implies the guys should be as vertical as practical, with the catenary insulation equipment being the impediment to this.

In some cases of shallow system depth at the SI, a special "fibrolite" shield was installed adjacent to the catenary insulation. Refer to *Figure 399*. I understand this was installed to protect the catenary insulation arrangement from damage due to excessive arcing "spatter" at the nearby arcing horns, caused by passing pantograph powering through the SI. Or maybe there's another reason?

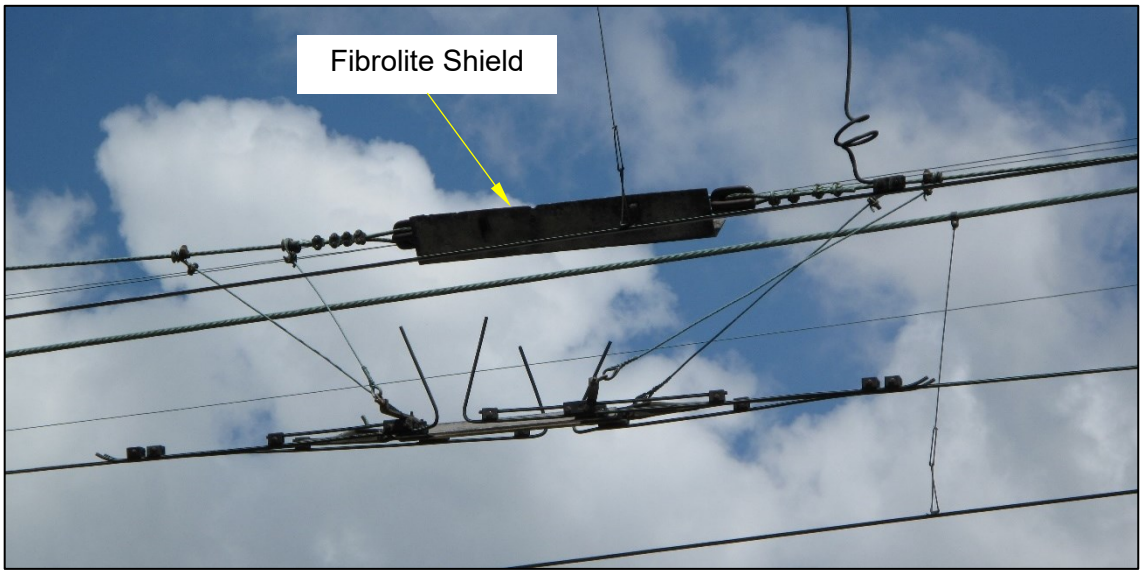


Figure 399 - Special shield installed to protect Catenary insulation

PERMALI BEAM DETERIORATION

The permali beams (cross-laminated timber) can deteriorate over time when exposed to the elements, particularly from UV radiation and water ingress (leading to dry rot).

So they need to be regularly inspected for signs of deterioration and replaced when required.

Figure 400 shows an instance where the beams had eventually snapped.

The view of the end of the beam displays the various cross laminations of timber that make up the beam.

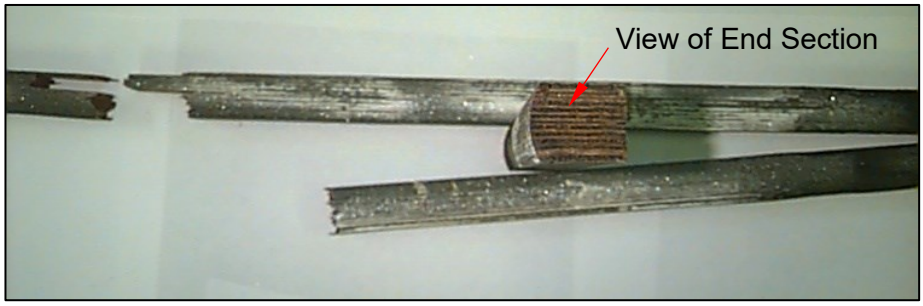


Figure 400 - Permali Beam damaged by separation (West Ryde, 1998)

3.6.1.6 Status (c. 2014)

The Type 5 SI is no longer installed because the insulating beam (permali) apparently cannot be sourced any longer. Its replacement is the Type 6 SI – see current standards.

A change-out program was instituted around 2012 to accelerate the replacement of all Type 5 SIs due to one particular incident around that time.

3.6.1.7 Reference

See *Table 34* for drawing reference.

3.6.2 Type 6 Section Insulator

3.6.2.1 Description

The Type 6 section insulator is manufactured by the French company "Jacques Galland", and is intended as a high speed section insulator, ideally suited to regulated OHW systems. It is shorter than the Type 5 SI and holds other advantages over it.

The Type 6 SI has been in use in Sydney since the mid-1980s. It came after the trialling of a several other SIs in an attempt to find something that was robust and performed better than a Type 5 SI when installed in the main line where traffic was at higher speeds. It also needed to cope with the fairly robust, heavy and closely-spaced freight train pantographs at the time.

The SI is rated to allow pantograph speeds of 120km/h in the "normal running direction", and 80km/h in the "reverse direction" (requiring the installation of the provided arcing horns).

It was named the Type 6 SI, obviously because it followed the Type 5 SI in acceptance into the network.

Over the past 35 years or so, it has proven to be a reliable piece of equipment with a good reputation (once some initial teething problems were overcome).

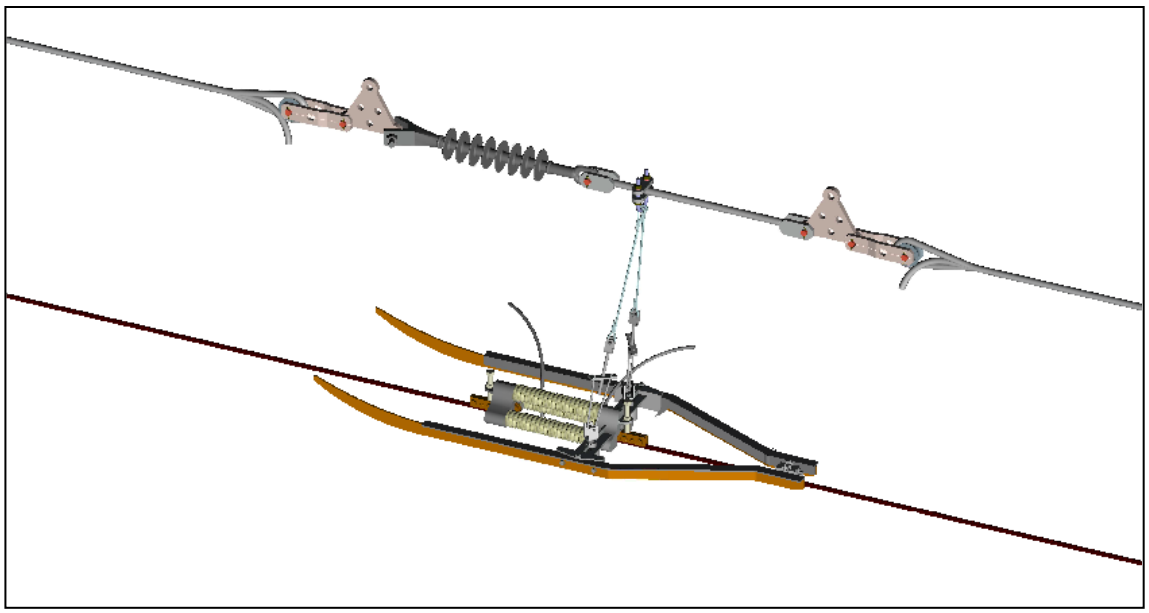


Figure 401 - Type 6 Section Insulator

3.6.2.2 Function

See *Section 3.6.0.2*.

3.6.2.3 Typical Components

Referring to *Figure 402*, typical components include:

- *Insulator & Body Frame.* This includes a trefoil arrangement of fibreglass insulators, which makes for an incredibly strong and stiff overall configuration. Importantly, it allows the side runners to be at the same height level as the contact wires (coplanar), unlike the Type 5 SI which has the runners 6mm or so lower. This is a real benefit especially for providing high speed operation. The body frame is made from cast aluminium, with recesses and holes at various places to attach the various other parts.

- *Contact Terminating Clamps*. These have deep teeth that lock into the top notch of the contact wire, with 4 bolts providing the locking power to hold the significant contact tension. A stainless steel pin at the other end of the clamp conveniently connects it to the SI frame. See *Figure 126* and *Figure 127* further back for what these clamps look like and where they fit.
- *Heel Clamp*. This clamp connects each of the side runners to the contact wire at the leading end of the SI. It also provides vertical alignment adjustment for getting the runners level with the contact wire at that point for smooth pantograph operation.
- *Side Runners*. These 2 hard solid lengths of copper (with the section shape of an inverted "T") hold the pantograph down as it traverses the length of the SI, especially over the air gap between the sectioned contact wires.
- *Guy wires*. These are stranded stainless steel wires about 5mm diameter, that support the weight of the SI, and provide correct lateral alignment of the runners to suit the pantograph on superelevated track. They include locally made turnbuckles to help achieve this lateral alignment.
- *Guy insulators*. These prevent any dc current from feeding through the stainless steel guy wires, which could otherwise cause them to eventually fail (I think due to embrittlement).
- *Catenary insulator*. This includes the insulator and associated catenary terminating hardware. These parts are all standard OHW kit used throughout Sydney's system.
- *Arcing horns*. These must be installed if it is ever likely that pantographs will travel in the *reverse* direction. An arc will always be struck if a train powers through the SI in this reverse direction. In this case, the arcing horns will attract the arc and guide it up and away from the trefoil insulators, extending its length in the process until it will rapidly extinguish.

3.6.2.4 Configuration

The Type 6 section insulator can be installed in both a single contact and a twin contact OHW system. It is lighter and shorter than the Type 5 SI.

The standard arrangement of the SI body is shown in drawing EL0166884 and the various configurations of its installation into the OHW, including support from catenary wire, are shown in drawing EL0030508.

It utilises a trefoil arrangement of fibreglass insulators (3 insulators in parallel) to establish a mechanically strong insulator group, which is able to resist the large bending forces imposed on it by the terminated contact wires located underneath.

The strong insulator enables a major benefit of this over other SIs – ***it has a flat contact profile***, i.e. the SI runners are configured to be at the same level as the contact wire entering and exiting the SI (coplanar). (Contrast this with the Type 5 SI above, which requires the runners to be about 6mm lower than the contact wire, which thus affects high speed performance.) This aspect makes the Type 6 SI suited to higher pantograph speeds, but only if installed in a regulated OHW system.

As mentioned above, it's rated for pantograph speeds of 120km/h in the *normal running direction*, and 80km/h in the *reverse direction*.

The SI is supported from the catenary and aligned by 2 guy wires which are located on the approach-end of the SI only.

Figure 403 shows the 3 position situations where the SI can be installed within a bay. Their intended designation is meant to be placed on the OHW layout calling them up:

- "**6-B**" – SI is located at or near the middle of the "B"ay. This is probably the most common situation.

- "**6-A**" – SI is located as close as practical to the "A"pproach side of a support & registration arrangement (i.e. at the end of the bay). This situation requires a minimum of 300mm electrical clearance from tips of runners to the S&R pull-off arms.
- "**6-D**" – SI is located as close as practical to the "D"eparture side of an S&R arrangement (i.e. at the start of the bay).

6-A and 6-D are commonly associated with feeding to the SI from an adjacent OHW structure, such as a portal (for cable feeding). Having the SI as close to the structure as is practical helps with the placement of aerial feeding down to the SI.

The main difference between all 3 is the way the catenary insulator termination fittings are configured. If you're not trying to place the insulator at either of the extreme ends of the bay, then the "6-B" designation is usually the most appropriate.

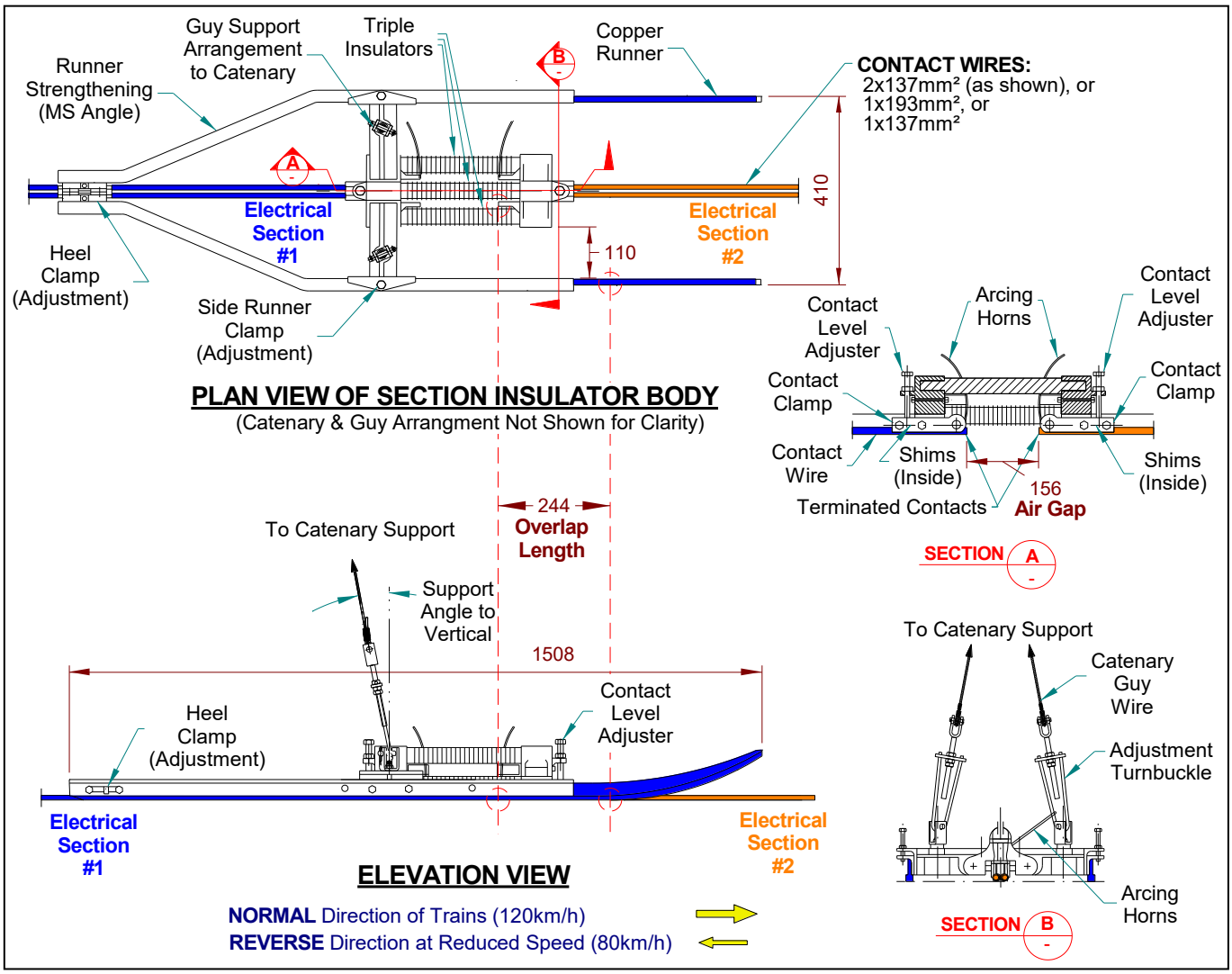


Figure 402 - Part-drawing of Type 6 Section Insulator

MODIFICATIONS

In the past, when the SI was received from the manufacturer it was modified fairly heavily to strengthen the arrangement and provide other enhancements to suit Sydney's OHW system. Recently a few of the changes were omitted, and the current list of modifications is listed in *Note 2* on the standard arrangement drawing EL0166884 revision "A".

One of the main improvements was to the copper runners, which had to be modified by incorporating galvanised mild steel angle strengtheners bolted to the runners. Any badly

worn dish-shaped carbon strips of pantographs (e.g. *Figure 63* much further back) travelling at speed could impact against the leading diagonal portion of the copper side runners, progressively deforming one or both diagonal copper runners in the process. These runners could deform so much as to then cause damage to subsequent pantographs. The steel strengtheners helped retain the diagonal copper shape, and this corrected the problem. The way the 2 side runners quickly branch out diagonally to the sides and to a greater separation (410mm), rather than having the gentler splay of the Type 5 SI (210mm), made the diagonal zone quite susceptible to this type of damage from our pantographs back then. (These distances are in *Figure 405*.)

The strengthening worked well over time.

However, recently this strengthening has become unnecessary, since the manufacturer has thickened the copper runners to become more robust. This was coupled with improvements made resulting in lighter and more tolerant pantographs now running around the system. This is a good outcome, as without the steel strengtheners, the weight of the SI is then much reduced, and this improves pantograph interaction at speed. Winners all around.

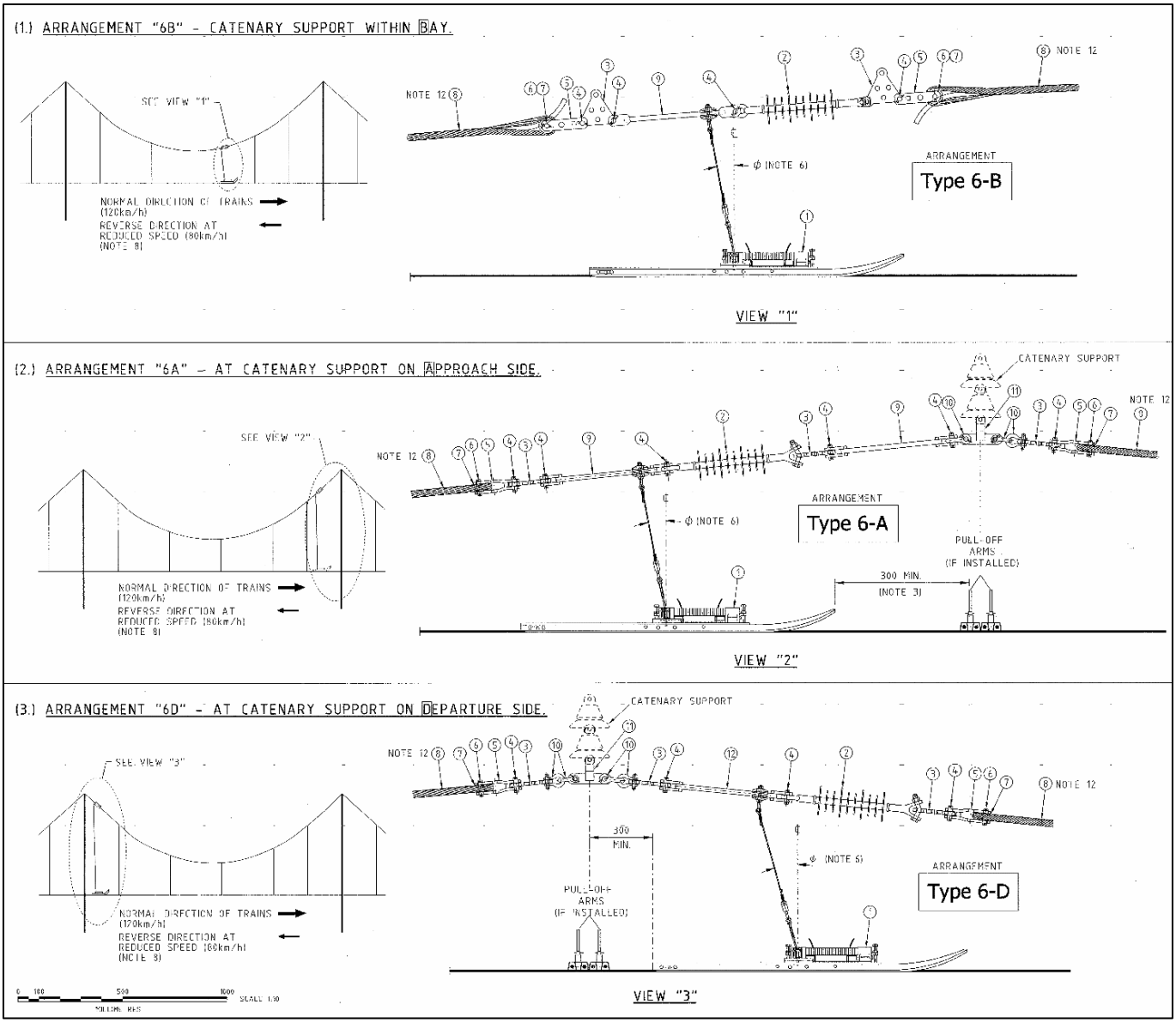


Figure 403 - 3 positions when installing a Type 6 SI (drawing EL0030508)

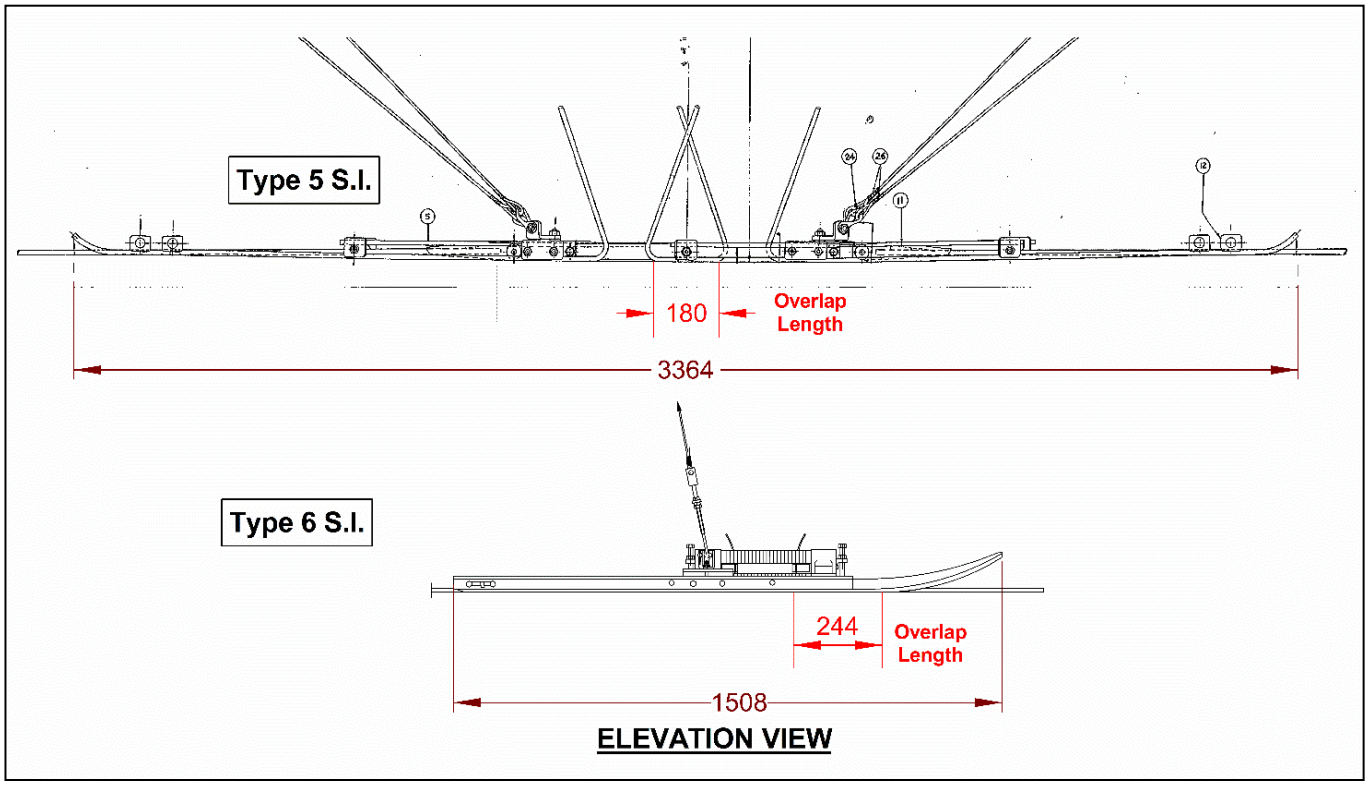


Figure 404 - Side view comparison of Type 5 & Type 6 Section Insulators

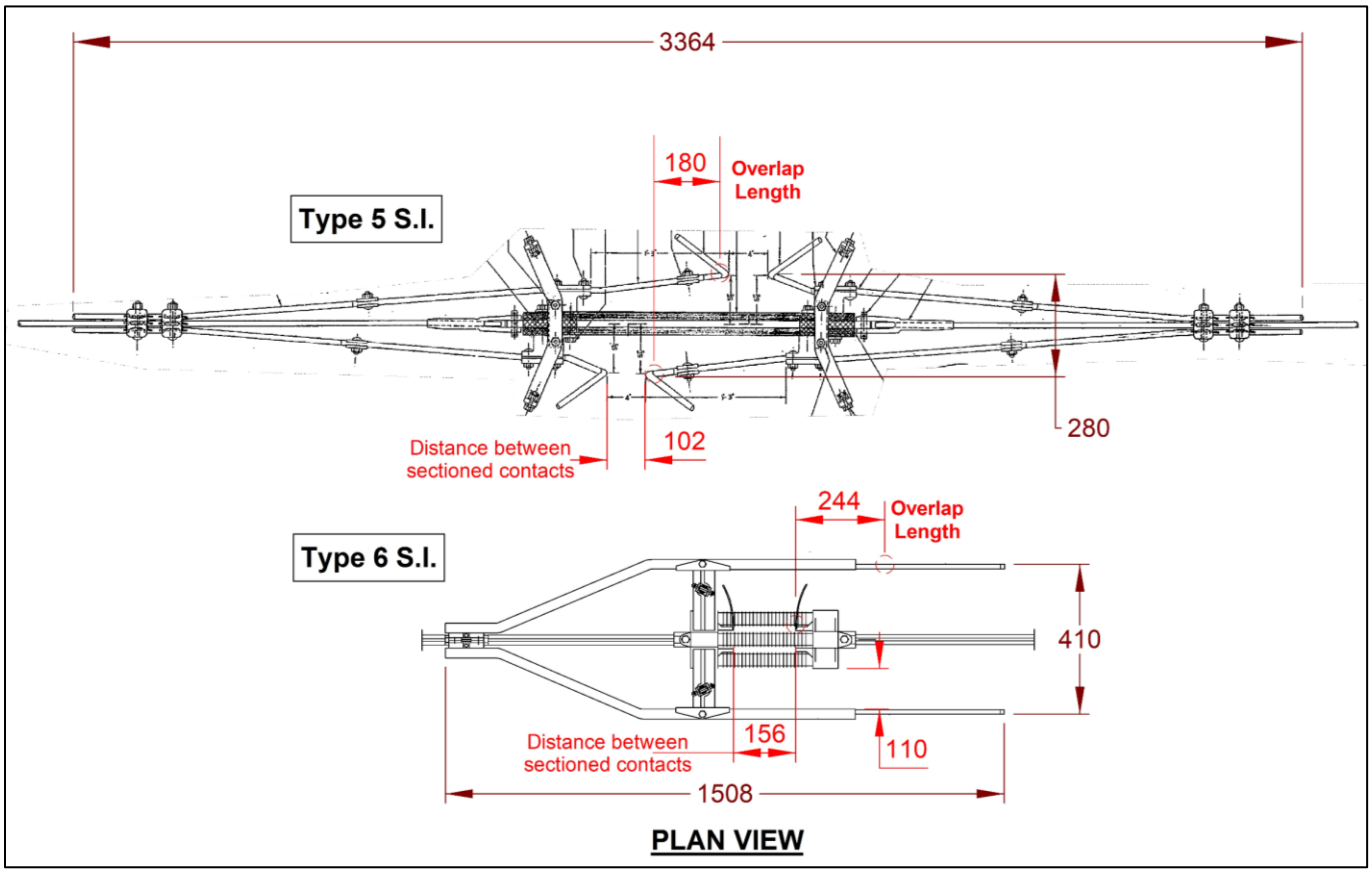


Figure 405 - Plan view comparison of Types 5 & 6 Section Insulators

Unlike the Type 5 SI which is supported by 4 guy wires – 2 on each side of the catenary insulator, the Type 6 SI requires only 2 support guys supported from the approach-side of the catenary insulator. This adds to the simplicity of the arrangement, although it's another thing

that people need to get right when installing (otherwise they may inadvertently short out the electrical sections).

Figure 404 (side view) and *Figure 405* (top view) give comparison of the size differences between the Type 5 and Type 6 section insulators.

The Type 6 SI is obviously a much more compact unit, but is wider in plan view – 410mm between runners – which is one of the main disadvantages of this SI (especially if "bowed" pantographs are being considered – refer *Section 6.3.2.1*, *A Proposed "Bowed" Pantograph Head*). But this 410mm figure is needed to achieve a reasonable electrical clearance between electrical sections (actually it's only 110mm, not 150mm, but this distance is next to the runners that can extinguish any established arc here).

In contrast, the Type 5 SI is only about 280mm wide (the newer SI on trial is also narrower).

3.6.2.5 Design Notes

Sectioning Distance

For the Type 6 SI, the distance between sectioned contact wires is about 156mm (*Figure 405*).

Shorting Distance

As with most section insulators, in order to provide a smooth mechanical path under the SI, a pantograph will momentarily short out the 2 electrical sections. This happens as the pantograph's pair of carbon strips bridge from the copper runners in one electrical section, to the contact wire of the next electrical section (in the normal running direction). See *Figure 392* for a view of the pair of typical carbon strips.

The amount of electrical overlap is about 244mm (see *"*Overlap Length*"* in *Figure 402*), plus the distance between the start and end of the carbon strip pair on each pantograph. (See also *Figure 690* much later on, which shows the typical relative distance between carbon strip pairs.)

Normal Running Direction

Contrary to what you might initially think, the *Normal* (preferred) running direction has the twin vertically-curved runners at the departure end of the SI. See *Figure 402* or *Figure 405*. Speeds up to 120km/h can be achieved in this direction.

In this preferred direction, any arc established after the electrical sections are bridged will be quickly extinguished as the pantograph passes beyond the curved-up runners. (Any arcing is effectively extinguished by the lengthening of the arc up the curved runners, which happens rapidly in this running direction.)

In contrast to the above, if a pantograph passes through in the *Reverse* direction, the arc is established between the 2 terminated ends of the contact wires (located about 155mm apart). See Section "A" in *Figure 402*. As the pantograph leaves one contact it draws the arc, which can continue even after the pantograph carbon strip reaches the other contact wire (the side runners are electrically connected). This is a fixed distance that can be too short to *quickly* extinguish an arc, even though it's slightly more than the minimum 150mm required by the standards. (I guess it's the numbers of such events that's of concern here, with each arcing event causing some damage in this area.)

So, if trains pass in this reverse direction then special *arcing horns* must be fitted (they are supplied with the SI). These horns can be simply bolted in place near the ends of the contact wire, and are designed to take the established arc out of this space and transfer it diagonally up and away from the insulators. In doing so, it also broadens the arc's length to a state where it cannot be sustained and so it extinguishes.

This arc extinguishing takes a split second to achieve, and it must be quick otherwise there would eventually be significant arcing damage to the SI.

PANTOGRAPHS POWERING THROUGH AN SI

Refer to *Figure 406*, which highlights the type of *arcing damage* to the underside of the aluminium body due to arc "spatter", as pantographs draw current when passing under the SI.

Spatter results when the plasma in an arc melts surrounding metal, causing this molten metal to sometimes fly off in all directions. The melting metal in this case can be the copper contact wire, steel arcing horns and/or aluminium SI body parts located near the place of arcing. Some minute amounts of this metal may also be deposited onto the roof of the passing trains and elsewhere in the immediate vicinity of the SI.

This particular SI in *Figure 406* was removed from Central Flyunders in 2004. The 2 views are of the underside of the SI – the left view is near the terminated contact wire and the right view is under one of the side support guy insulators. They show the aluminium body being severely pitted and eroded due to the passage of probably many hundreds of thousands of pantographs powering heavily through the SI outside the major feeding substation at Central (Prince Alfred Substation). When a train accelerates and draws significant current as it passes under an SI, a large but brief arc can establish, and is often accompanied by a short but loud sound of the arcing momentarily taking place. It's good to know that, as bad as it looks, this SI did not fail in service – it was renewed when the OHW was renewed and regulated.

Figure 406 - Underside of a Type 6 SI showing excessive pitting due to arc spatter

When new, the top of the pantograph's carbon strips should be flat over their length, but frictional wear from the contact wire towards the middle portion (±300mm of centre) causes the carbon strips in this area to eventually be slightly dished (e.g. *Figure 63* much further back). When this happens, some arcing under the SI can occur also in the *normal* running direction (which, according to the manufacturer, does not require the arcing horns). The cumulative effect over the years can lead to the sort of damage shown in *Figure 406*. (Interestingly, the SI was removed, not necessarily based on the condition of SI, but because the OHW was being upgraded from fixed-anchored to a new regulated OHW system at that time.)

The way the 2 side runners quickly branch out to the sides (rather than the gentler splay of the Type 5 SI) means any wear on the pantograph's carbon strip and/or misalignment on the runners, can cause the SI to be jolted around as a fast pantograph runs along the underside of

the SI, and this can lead to momentary disconnections and consequent arcing and sputter, even in the *normal* running direction.

See *Figure 407* for the sort of carbon strip wear pattern that can cause arcing problems when interacting with the SI in the reverse direction, in the region of the "Overlap Length" as depicted in *Figure 402*. The dimension shown as "vertical gap between contact and pantograph" is a concern. This is where an arc, if established, can do significant damage if the pantograph passes through very slowly (or worse still, parks under the SI). It may be possible that the arcing horns draw this arc away and deal with it – hopefully.

Of course, this also depends on the amount of current being fed through the carbon strips from one electrical section to the next – if there's no current, there should be no arcing.

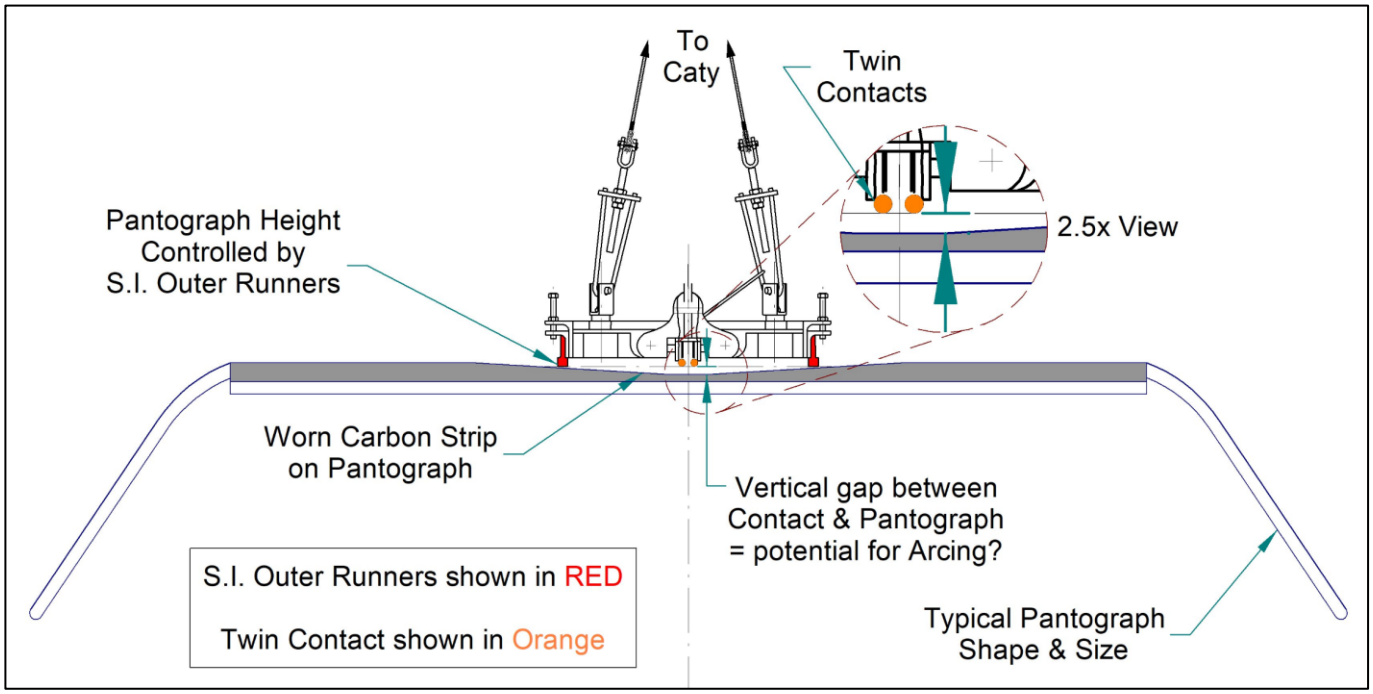

To Caty
Twin Contacts
2.5x View
Pantograph Height Controlled by S.I. Outer Runners
Worn Carbon Strip on Pantograph
Vertical gap between Contact & Pantograph = potential for Arcing?
S.I. Outer Runners shown in RED
Twin Contact shown in Orange
Typical Pantograph Shape & Size

Figure 407 - End View of SI showing vertical gap to Contacts due to worn pantograph

ALIGNMENT ADJUSTMENT

This SI has a number of adjustments that can be made. These need to be accurately set to get the alignment correct for higher speed operation, otherwise there'll probably be a lot of arcing, OHW movement and noise as the pantographs pass through.

More importantly, if not correctly set up, parts of the SI will quickly wear and may actually cause the SI to fail and/or damage passing pantographs, before being detected and corrected.

It is imperative that any adjustments are locked off using some reliable means of ensuring they don't come loose over time. (Any loose fittings in the OHW will eventually wear out.)

3.6.2.6 Status (c. 2014)

The Type 6 SI is intended for use in a regulated OHW system, but can also be installed in a fixed-anchored system provided it's at somewhat reduced speeds and the design has been checked out for suitability in that area.

The added strengthening of the SI (performed locally) is no longer required.

3.6.2.7 Reference

See *Table 34* for drawing reference.

3.6.3 BICC (Compound) Section Insulator

3.6.3.1 Description

The BICC section insulator was developed for the compound OHW system which exists from Emu Plains to Lithgow over the Blue Mountains. See *Figure 408*.

3.6.3.2 Function

See *Section 3.6.0.2*.

3.6.3.3 Typical Components

The components are quite similar to those needed for the Type 5 SI, but with additional hardware to deal with terminating the auxiliary catenary wire on both ends of the SI.

3.6.3.4 Configuration

This section insulator is similar in appearance to the Type 5 SI.

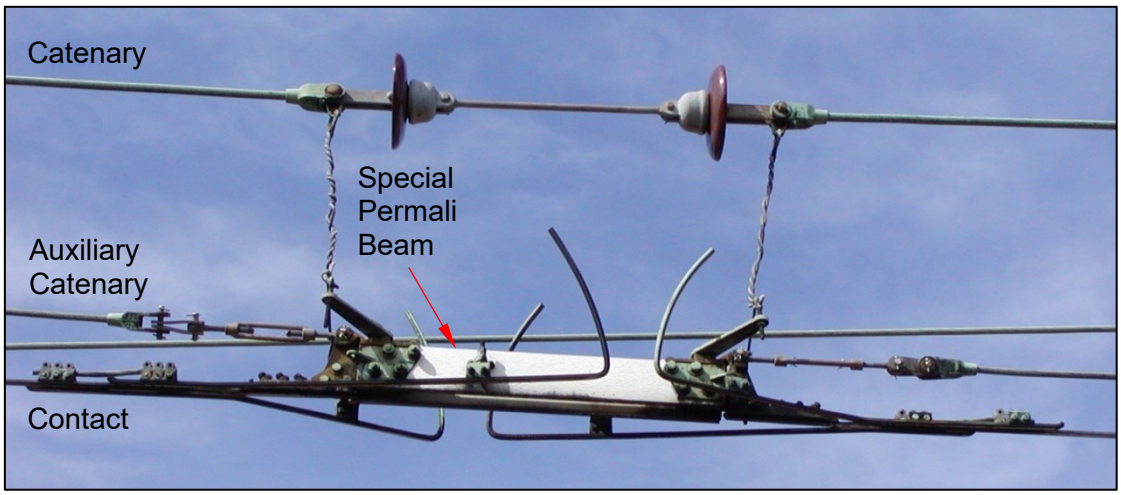


Figure 408 - Compound SI

At each end of the SI body, the auxiliary catenary and contact wires are terminated onto a common gunmetal casting that then grips the permali beams. These beams are about twice as high as the normal permali beam used in the Type 5 SI, most likely for the added tensile strength needed with the additional terminated conductor and at a higher height.

Like the Type 5 SI, the side runners push the pantograph down as they pass through, probably by a similar 6mm (1/4") figure.

The arrangement is shown in *Figure 409* (which doesn't include the catenary arrangement.)

3.6.3.5 Design Notes

A Type 6 SI was adapted to suit the compound OHW system (with additional K-Line insulator to handle the aux. catenary wire) – refer to drawing EL0052290 (*Figure 410*).

3.6.3.6 Status (c. 2014)

This SI can only to be used in the Compound OHW system.

A modified Type 6 SI arrangement was developed for use in the Compound OHW system in certain circumstances – drawing EL0052290.

3.6.3.7 Reference

See *Table 34* for drawing reference.

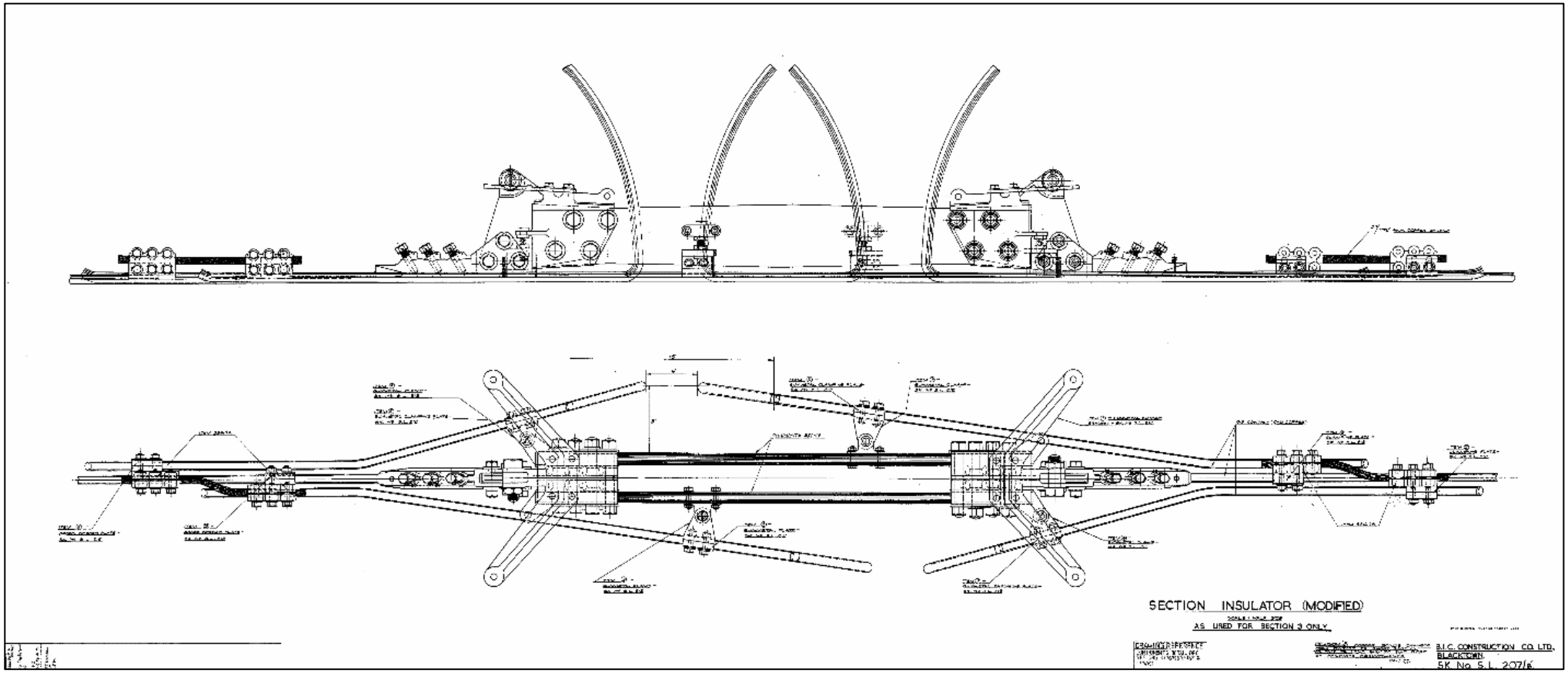
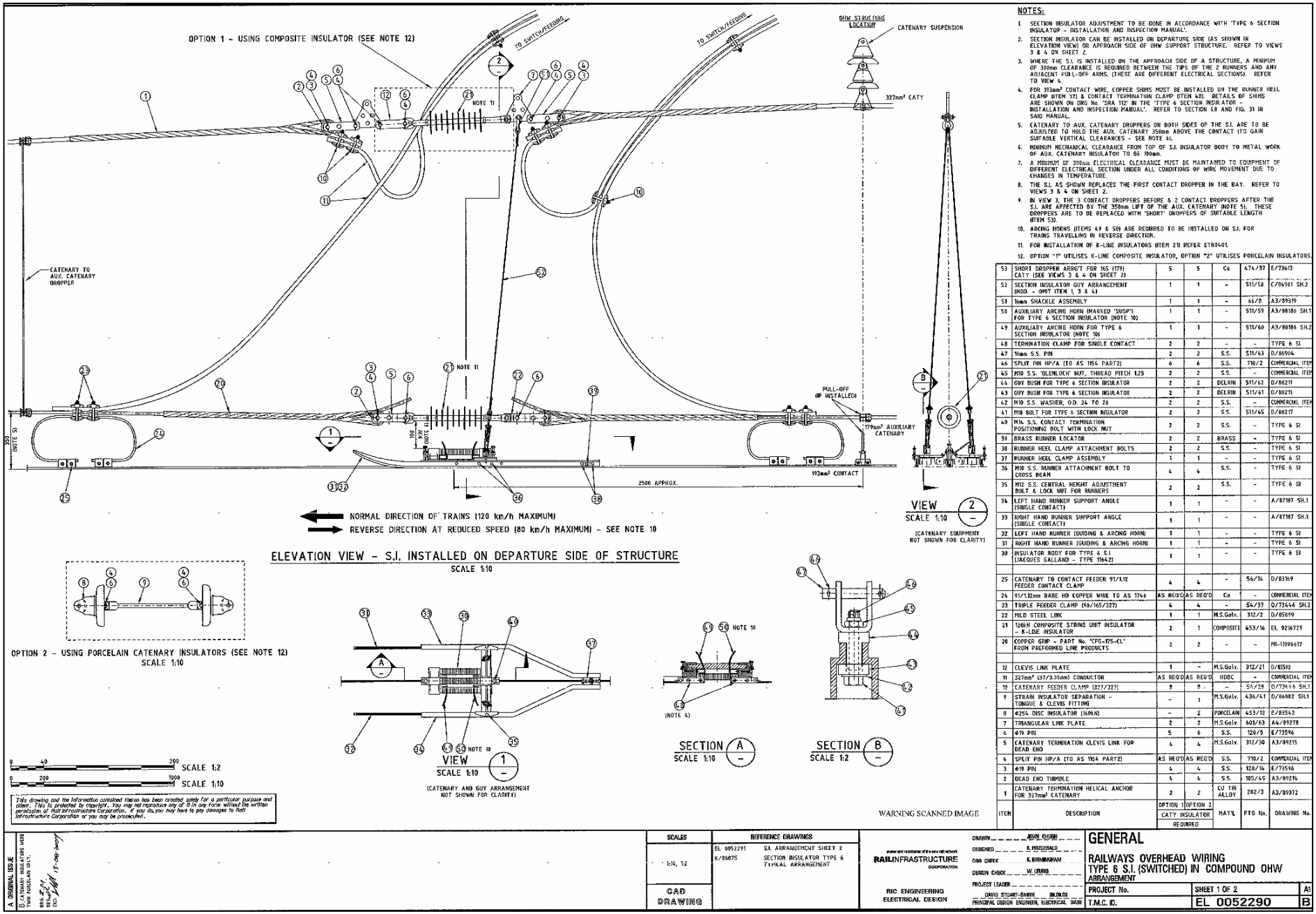


Figure 409 - Section Insulator for Compound OHW – old drawing (Catenary not shown)



NOTES:

1. SECTION INSULATOR ADJUSTMENT TO BE DONE IN ACCORDANCE WITH 'TYPE 6 SECTION INSULATOR - INSTALLATION AND INSPECTION MANUAL'.
2. SECTION INSULATOR CAN BE INSTALLED ON DEPARTURE SIDE (AS SHOWN IN ELEVATION VIEW) OR APPROACH SIDE OF OHW SUPPORT STRUCTURE. REFER TO VIEWS 3 & 4 ON SHEET 2.
3. WHERE THE S.I. IS INSTALLED ON THE APPROACH SIDE OF A STRUCTURE, A MINIMUM OF 300mm CLEARANCE IS REQUIRED BETWEEN THE TIPS OF THE 2 RUNNERS AND ANY ADJACENT PULL-OFF ARMS. (THESE ARE DIFFERENT ELECTRICAL SECTIONS). REFER TO VIEW 4.
4. FOR 193mm² CONTACT WIRE, COPPER SHIMS MUST BE INSTALLED ON THE RUNNER HEEL CLAMP (ITEM 37) & CONTACT TERMINATION CLAMP (ITEM 40). DETAILS OF SHIMS ARE SHOWN ON DRG No. 'SRA 112' IN THE 'TYPE 6 SECTION INSULATOR - INSTALLATION AND INSPECTION MANUAL'. REFER TO SECTION 18 AND FIG. 31 IN SAID MANUAL.
5. CATENARY TO AUX. CATENARY DROPPERS ON BOTH SIDES OF THE S.I. ARE TO BE ADJUSTED TO HOLD THE AUX. CATENARY 350mm ABOVE THE CONTACT TO GAIN SUITABLE VERTICAL CLEARANCES - SEE NOTE 8.
6. MINIMUM MECHANICAL CLEARANCE FROM TOP OF S.I. INSULATOR BODY TO METAL WORK OF AUX. CATENARY INSULATOR TO BE 190mm.
7. A MINIMUM OF 300mm ELECTRICAL CLEARANCE MUST BE MAINTAINED TO EQUIPMENT OF DIFFERENT ELECTRICAL SECTION UNDER ALL CONDITIONS OF WIRE MOVEMENT DUE TO CHANGES IN TEMPERATURE.
8. THE S.I. AS SHOWN REPLACES THE FIRST CONTACT DROPPER IN THE BAY. REFER TO VIEWS 3 & 4 ON SHEET 2.
9. IN VIEW 3, THE 3 CONTACT DROPPERS BEFORE & 2 CONTACT DROPPERS AFTER THE S.I. ARE AFFECTED BY THE 350mm LIFT OF THE AUX. CATENARY (NOTE 5). THESE DROPPERS ARE TO BE REPLACED WITH 'SHORT' DROPPERS OF SUITABLE LENGTH (ITEM 53).
10. ARCING HORNS (ITEMS 49 & 50) ARE REQUIRED TO BE INSTALLED ON S.I. FOR TRAINS TRAVELLING IN REVERSE DIRECTION.
11. FOR INSTALLATION OF K-LINE INSULATORS (ITEM 21) REFER ETN3401.
12. OPTION "1" UTILISES K-LINE COMPOSITE INSULATOR, OPTION "2" UTILISES PORCELAIN INSULATORS.

ITEM	DESCRIPTION	OPTION 1 CATY INSULATOR REQUIRED	OPTION 2 CATY INSULATOR REQUIRED	MAT'L	FTG No.	DRAWING No.
53	SHORT DROPPER ARRG'T FOR 16S (179) CATY (SEE VIEWS 3 & 4 ON SHEET 2)	5	5	Cu	474/37	E/73613
52	SECTION INSULATOR GUY ARRANGEMENT (MOD. - OMIT ITEM 1, 3 & 4)	1	1	-	511/58	C/86981 SH.2
51	16mm SHACKLE ASSEMBLY	1	1	-	66/8	A3/89319
50	AUXILIARY ARCING HORN (MARKED 'SUSP') FOR TYPE 6 SECTION INSULATOR (NOTE 10)	1	1	-	511/59	A3/88188 SH.1
49	AUXILIARY ARCING HORN FOR TYPE 6 SECTION INSULATOR (NOTE 10)	1	1	-	511/60	A3/88188 SH.2
48	TERMINATION CLAMP FOR SINGLE CONTACT	2	2	-	-	TYPE 6 SI
47	16mm S.S. PIN	2	2	S.S.	511/63	D/86904
46	SPLIT PIN HP/A (TO AS 1954 PART2)	6	6	S.S.	710/2	COMMERCIAL ITEM
45	M10 S.S. 'GLEMLOCH' NUT, THREAD PITCH 1.25	2	2	S.S.	-	COMMERCIAL ITEM
44	GUY BUSH FOR TYPE 6 SECTION INSULATOR	2	2	DELRIN	511/62	D/88211
43	GUY BUSH FOR TYPE 6 SECTION INSULATOR	2	2	DELRIN	511/61	D/88211
42	M10 S.S. WASHER, O.D. 24 TO 28	2	2	S.S.	-	COMMERCIAL ITEM
41	M10 BOLT FOR TYPE 6 SECTION INSULATOR	2	2	S.S.	511/65	D/88217
40	M16 S.S. CONTACT TERMINATION POSITIONING BOLT WITH LOCK NUT	2	2	S.S.	-	TYPE 6 SI
39	BRASS RUNNER LOCATOR	2	2	BRASS	-	TYPE 6 SI
38	RUNNER HEEL CLAMP ATTACHMENT BOLTS	2	2	S.S.	-	TYPE 6 SI
37	RUNNER HEEL CLAMP ASSEMBLY	1	1	-	-	TYPE 6 SI
36	M10 S.S. RUNNER ATTACHMENT BOLT TO CROSS BEAM	4	4	S.S.	-	TYPE 6 SI
35	M12 S.S. CENTRAL HEIGHT ADJUSTMENT BOLT & LOCK NUT FOR RUNNERS	2	2	S.S.	-	TYPE 6 SI
34	LEFT HAND RUNNER SUPPORT ANGLE (SINGLE CONTACT)	1	1	-	-	A/87187 SH.1
33	RIGHT HAND RUNNER SUPPORT ANGLE (SINGLE CONTACT)	1	1	-	-	A/87187 SH.2
32	LEFT HAND RUNNER (GUIDING & ARCING HORN)	1	1	-	-	TYPE 6 SI
31	RIGHT HAND RUNNER (GUIDING & ARCING HORN)	1	1	-	-	TYPE 6 SI
30	INSULATOR BODY FOR TYPE 6 S.I. (JACQUES GALLAND - TYPE 11642)	1	1	-	-	TYPE 6 SI
25	CATENARY TO CONTACT FEEDER 91/3.12 FEEDER CONTACT CLAMP	4	4	-	56/14	D/83369
24	91/3.12mm BARE HD COPPER WIRE TO AS 1746	AS REQ'D	AS REQ'D	Cu	-	COMMERCIAL ITEM
23	TRIPLE FEEDER CLAMP (90/165/327)	4	4	-	54/37	D/73446 SH.2
22	MILD STEEL LINK	1	1	M.S.Galv.	312/2	D/85099
21	126kN COMPOSITE STRING UNIT INSULATOR - K-LINE INSULATOR	2	1	COMPOSITE	453/16	EL 9216729
20	COPPER GRIP - PART No. 'CPG-875-CL' FROM PREFORMED LINE PRODUCTS	2	2	-	-	MI-11986617
12	CLEVIS LINK PLATE	1	-	M.S.Galv.	312/21	D/85502
11	327mm² (37/3.35mm) CONDUCTOR	AS REQ'D	AS REQ'D	HDBC	-	COMMERCIAL ITEM
10	CATENARY FEEDER CLAMP (327/327)	8	8	-	54/28	D/73446 SH.1
9	STRAIN INSULATOR SEPARATION - TONGUE & CLEVIS FITTING	-	1	M.S.Galv.	436/41	D/86082 SH.1
8	ø254 DISC INSULATOR (160kN)	-	2	PORCELAIN	453/12	E/89542
7	TRIANGULAR LINK PLATE	2	2	M.S.Galv.	601/63	A4/89278
6	ø19 PIN	5	6	S.S.	120/5	E/73596
5	CATENARY TERMINATION CLEVIS LINK FOR DEAD END	4	4	M.S.Galv.	312/30	A3/89215
4	SPLIT PIN HP/A (TO AS 1954 PART2)	AS REQ'D	AS REQ'D	S.S.	710/2	COMMERCIAL ITEM
3	ø19 PIN	4	4	S.S.	120/14	E/73596
2	DEAD END THIMBLE	4	4	S.S.	105/45	A3/89294
1	CATENARY TERMINATION HELICAL ANCHOR FOR 327mm² CATENARY	2	2	CU TIN ALLOY	282/3	A3/89372

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WARNING SCANNED IMAGE

A ORIGINAL ISSUE
B CATENARY INSULATORS WERE TYPE PORCELAIN (SI.)

SCALES: 1:10, 1:2
CAD DRAWING

REFERENCE DRAWINGS
EL 0052291 S.I. ARRANGEMENT SHEET 2
R/86075 SECTION INSULATOR TYPE 6 TYPICAL ARRANGEMENT

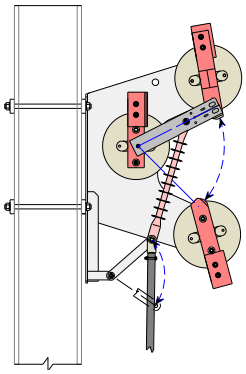
owner and maintainer of the rail network
RAILINFRASTRUCTURE CORPORATION
RIC ENGINEERING ELECTRICAL DESIGN

DRAWN JOHN CHOW
DESIGNED K. FITZGERALD
DRG CHECK K. BIRMINGHAM
DESIGN CHECK W. LEUNG
PROJECT LEADER
DAVID STUART-SMITH
PRINCIPAL DESIGN ENGINEER, ELECTRICAL

GENERAL
RAILWAYS OVERHEAD WIRING
TYPE 6 S.I. (SWITCHED) IN COMPOUND OHW ARRANGEMENT
PROJECT No. SHEET 1 OF 2 A1
T.M.C. ID. EL 0052290 B

Figure 410 - Type 6 SI substitute for the Compound OHW system

3.7 SWITCHES



3.7.0 General

3.7.0.1 Description

1500V OHW switches are usually installed adjacent to the track, and located towards the top of a mast or portal leg at about catenary wire height. They can be installed on a tunnel wall (clear of the track), on a concrete support column, etc. They can also appear in "banks" of 2 or more switches installed on a purpose-built steel structure.

A switch arrangement will have aerial feeder wires connecting the OHW conductors to the switch, either directly or via a cable feeding arrangement (using pairs of 400mm² cables).

The standard mast mounted switch is operated by a *handle mechanism* located about 1 metre above ground level for operator convenience. The operator stands on an "equipotential mat" to operate the switch. A vertical *operating rod*, about 5m in length, connects the operating handle to the switch above. See photo to right (an isolating & rail-connecting switch).

A switch is usually "locally" controlled (i.e. a switch operator is required on site). However, some switches can be configured to be "remotely" controlled, with appropriate electric motors and control technology housed in a metal box about 1m above ground.

Although there are likely a few other types of very old switches still existing at a few scattered locations around Sydney's OHW system, there are 4 main styles of switches, and these will be described further in the subsequent subsections (in chronological order):

- The old "Railway" switch (which dates back many decades),
- The "BICC" switch (located primarily in the Compound OHW system west of Penrith in the Blue Mountains).
- The "Edward Keller" switch (introduced in late 1970s or early 80s), and
- The "ART" Switch (was "Multi-Contact"), which was introduced in the 1990s, and remains the current *standard* switch for use in new OHW (see picture to the right).

Figure 411 - A typical modern 1500V switch on a portal leg

3.7.0.2 Function

A 1500V switch has either 2 or 3 terminals, including a *Common* terminal which connects to the pivot of a pivoting copper blade. See *Figure 412* and *Figure 413*, which show a typical 3 terminal switch. (This "ART" switch was chosen because it's easy to describe its workings.)

Such a switch, configured as "Isolating & Rail-Connecting", provides the following functions:

- When *CLOSED* – Blade is in Up position (as shown) and it can pass heavy current at 1500Vdc, from S/S or S/H supply (Top terminal) to one electrical section (Pivot terminal).
- When *OPEN* – Blade is in midway position, so it can isolate the 1500V supply to an electrical section.
- When *CLOSED TO RAIL* – Blade is in the Down position connected to the Rail terminal, so a "rail-connecting" switch can also connect a de-energized section of OHW to rail.

The switch incorporates appropriate 1500V insulation between the switch terminals and blade mechanism to the switch support frame, and also from the blade to the operating rod and handle mechanism below.

These switches are designed to either pass heavy current from one electrical section to the next (or to rail), or to isolate these sections.

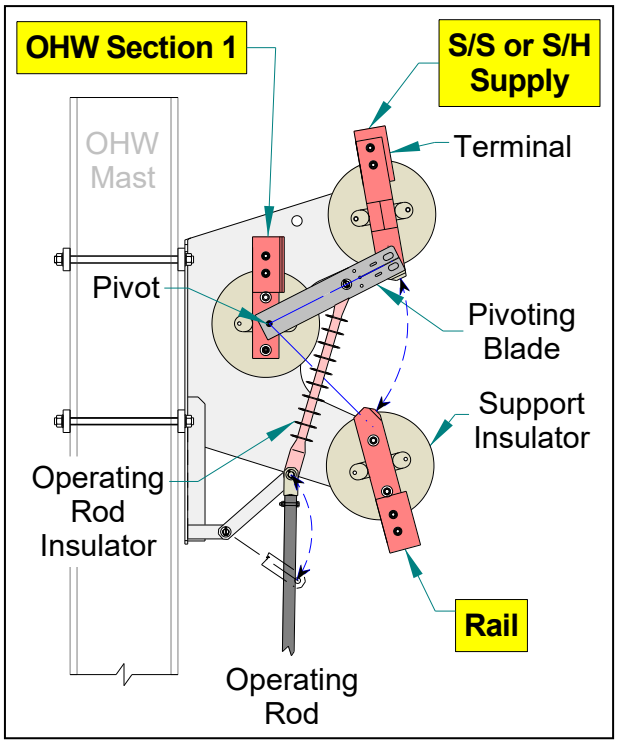


Figure 412 - Typical switch terminals

These types of switches are not designed to be opened when passing dc current, for to do so would result in an arc commencing the moment a gap opens at the contacts. This arc would be difficult to quench, and may result in subsequent contact damage and possible injury to the operator below (due to any molten metal). Note that switches which open under load need to be specially designed because it is extremely difficult to interrupt a dc arc quickly! (You only need to look at the complexity of a dc Circuit Breaker inside a substation to begin to understand the onerous task of interrupting heavy dc currents – see *Section 6.1.1* for more.)

Having said that, there have been a few switches with special metal arcing horns or "stingers" (I think they were called), which are whisker-like rods located near the ends of the contacts. They're designed to flick open quickly to a wide separation as the switch is opened. In this way, any *small level* of current that may be in the circuit being interrupted, will draw an arc as the contacts begin to open. The arc then transfers to the arcing horns, which then separate quickly to a greater distance than the arc can be sustained, and so it's extinguished. The arcing horns are made from a high melting point metal to minimise spark erosion over many switching operations. But again, they're not designed for opening load currents – that's what DCCBs inside substations and sectioning huts need to do.

It seems that the best opening and closing outcomes are achieved by quick and deliberate actions at the operating handle (without overdoing it of course). When closing, the blade needs to be quickly and fully inserted into its terminal connector (for heavy currents). When opening, the blade should quickly retract from the connector to open the circuit – if there's any tendency to draw a low-level arc when this happens, this action should quickly interrupt its formation. However, refer to the Standards for the correct operating procedure.

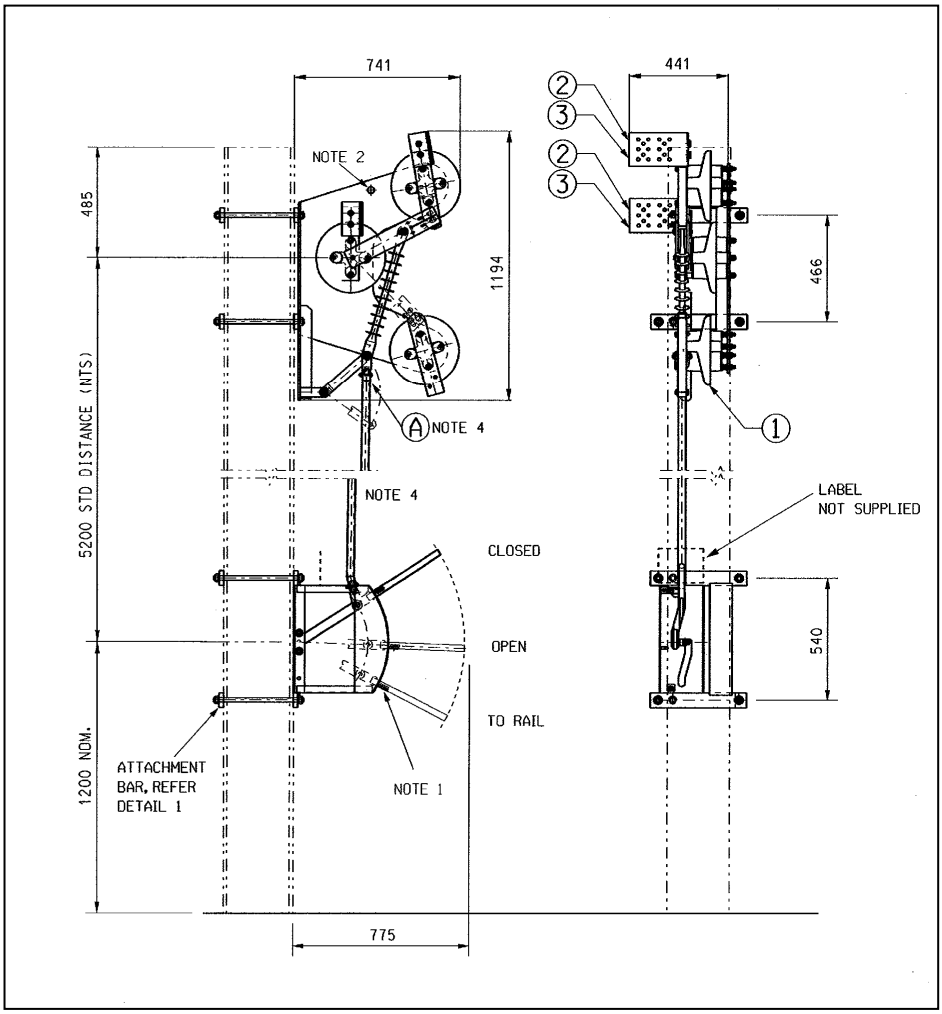


Figure 413 - Various dimensions of an Isolating & Rail-Connecting Switch (ART Switch)

3.7.0.3 Typical Components

The following components are common to most switch arrangements:

- *Switch frame*. This is used for directly mounting switch hardware such as insulators, pivot connections, etc. Its rigid frame is capable of taking the loads when operating the switch, without causing excessive deflections (which might otherwise cause the switch blade to not line up with its connectors). The frame is also made to suit installation of the switch assembly onto some standard OHW structure such as a mast.
- *Support insulators*. These are used to support the heavy duty switch terminals, the finger contacts and also the pivoting switch blade. The switches typically have 2 insulators (if it's an isolating switch only) or 3 insulators (if it's isolating and connecting to rail, etc.).
- *Switch contacts*. The contacts are where the circuit is actually made or broken. They are typically made from silver alloy or copper with silver coating, and are relatively large in size to help provide a low resistance connection. Silver is used because it's a better heat transfer and electrical conductor than copper. The contacts often employ a number of special spring-loaded fingers that accept the switch blade. The fingers ensure that a significant pressure is applied from their contact area to the blade, to help lower the contact resistance when the switch is closed. This avoids overheating when the switch passes heavy current over a significant period of time.
- *Switch blade*. This part is usually made from copper which is silver-coated in areas where good electrical contact is required. The blade rotates about a pivot and is responsible for

making or isolating the circuit. A special pivoting assembly allow this rotation to take place while also providing a good electrical connection to its electrical terminal.

- *Feeder connections*. These are terminal connections attached to the various contacts of the switch. They allow connections to be made to cable lugs and/or aerial feeder wires. For the past 20 years or so, switch terminals include a special hole pattern to drawing EL0476704, to accept the standard twin U-bolt connections for aerial feeders (with holes spaced 45mm apart and in 90°, 180° and 270° orientation directions), or the twin cable lugs (each with 2 holes 50mm apart). This hole pattern can be seen a bit further on in *Figure 416*. So, there's provision for:
  - Cable lugs for twin 400mm² cable connection, back to S/S or S/H or a local switch or local inter-switch cabling.
  - Twin 270mm² HDBC aerial feeder connection to the OHW.
  - 90mm² or 120mm² rail-connecting cable.
- *Operating rod*. This is a vertical rod made from metal or fibreglass (or wood in the old days) that is used to change the position of the switch blade. The lower end of the rod connects to the *operating handle* located about 1m above ground where the operator stands when operating the switch. The top of any metal operating rod connects to the blade though a 1500V insulator. The vertical rod can be 6m or longer, and can sometimes be so long as to require an intermediate pivot point (attached to mast) to prevent excessive flexing and more precise control of the switch operation.
- *Operating handle mechanism*. This normally consists of a pivoting steel rod "handle" that moves up or down to various switch positions, e.g. "Connected", "Isolated" or "Rail-Connected". It includes labelling of the appropriate Electrical Sectioning Number being actioned, as well as labelling of the various switch positions. These are most important.
- *Switch operator's platform*. This steel platform (or mat) is where the operator stands while operating the switch. There is an "equipotential" heavy gauge electrical bond connecting the mat to the operating handle, to keep the mat at the same electrical potential as the handle being operated. In this way there can be no electric shock to the operator in the unlikely event of a 1500V electrical fault to ground at that time.

There have also been a few situations that have also called for a *clear polycarbonate screen* (barrier) to be located under and in front of a 1500V switch. The clear screen allows the operator to see the switch position and its operation, which is important. The barrier aspect is apparently to help protect the switch operator against possible molten metal "spatter" (copper or silver) falling onto the operator, which may result from arcing if the switch is inadvertently opened whilst carrying any significant dc current. Sometimes this screen has been included if the switch is located in close proximity to the operator (which might pose an increase risk).

A polycarbonate screen has also apparently been installed in situations where the openable top windows of a double deck train (only on older trains now) could possibly allow a person to extend their arm outside the carriage, and come too close to live parts of a 1500V switch. The screen again acts as a barrier, but this time it's installed to keep people away from the hazard. An example of this situation was meant to be installed at No. 3 Platform, Wynyard Station.

3.7.0.4 Configuration

The switch usually connects to the catenary via a pair of aerial feeder wires. Alternatively, 1500V insulated cables can be used from the switch at a remote location, to a position above the OHW being fed, to a *cable-to-aerial termination*, then twin aerial conductors drop down to connect to the catenary.

The various main 1500V OHW switches are listed in *Table 36*.

TMP Code	Equipment Name	Made By	Drawing No.
EP-08-36-00-00	**1500V Switch Arrangement**		
EP-08-36-01-00	*1,000 or 2,000 Amp Sectioning Switch*	*RailCorp*	*C/56457,(1000 A), C/74271 (2000 A), E/61439 (arrangement)*
EP-08-36-11-00	*Combined Sectioning / Rail-Connecting Switch*	*RailCorp*	*C/57420, E/74221 Sh.1*
EP-08-36-31-00	*BICC Sectioning Switch*	*BICC*	*C/74775*
EP-08-36-32-00	*BICC Combined Sectioning / Rail-Connecting Switch*	*BICC*	*C/74775*
EP-08-36-41-00	*Remotely Controlled Sectioning Switch*	*Various*	
EP-08-36-45-00	*Remotely Controlled Isolating & Rail-Connecting Switch – Edward Keller*	*EK*	
	ART Switch – Isolating/Rail-Connecting (L&R) *ART Switch – 2 Position (L & R)* *ART Switch – 2 Pole (L & R)* *ART Switch – Rail-Connecting (L & R)*	*ART*	*EL0057425, EL0077250, EL0282734, EL0282735, EL0077251, EL0077252, EL0282806, EL0282807*

Table 36 - Various Switch arrangements

Table 37 is intended to just give an idea of how many sectioning switches were installed in 2012. With all the recent improvements brought to Sydney's rail system since then, these the numbers are now likely to be much larger.

District	Approx. No. of Sectioning Switches *	Comment
North	185	
Central	262	
West	172	
Illawarra	117	
Total	**736**	

* As at 2012 – obtained from RailCorp Asset Explorer.

Table 37 - Sectioning Switch population by District (c. 2012)

From the above table, the current left-hand & right-hand 1500V Switches (from ART) are:

- Combined Sectioning & Rail-Connecting Switch – EL0057425 & EL0077250
- Sectioning Switch – EL0077251 & EL0077252
- 2 Position Switch (Feeder 1 & Feeder 2) – EL0282734 & EL0282735
- Rail-Connecting Switch – EL0282806 & EL0282807

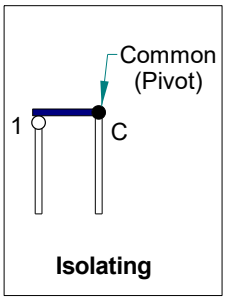
A typical Switch Arrangement drawing that shows how the switch connects to the OHW is included in *Figure 727* near the end of this document.

3 SWITCH CONFIGURATION VARIABLES

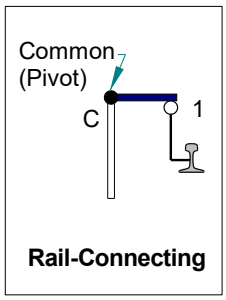
There seem to be at least 3 main variables for switch configurations, namely the ***type of connection*** to the OHW, the switch ***operating mechanism*** and the switch ***rating***. These are now detailed.

1. ***Type of connection to OHW*** – The switch can be connected with the following 4 configurations:

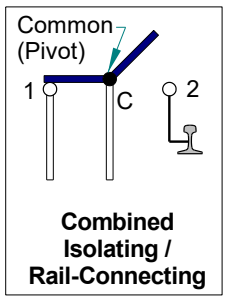
   a) *Isolating* – The switch connects from one OHW electrical section to another. This is done normally over a section insulator or a sectionable overlap, but can also connect OHW over one track to OHW over another track. The switch only needs 2 terminals.
   Symbol:



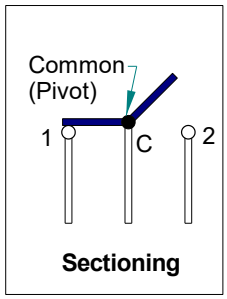
   b) *Rail-Connecting* – In the closed position, this type of switch arrangement connects the OHW to rail (i.e. "rail-connected"). The OHW must be isolated from supply before the switch is operated to the "To Rail" position. The switch only needs 2 terminals.
   Symbol:



   c) *Combined Isolating / Rail-Connecting* – This common type of switch has 2 "closed" states and an intermediate "open" state, and provides a combination of the above 2 functions.
   One closed state ("*Closed*") connects one OHW electrical section to the next section, and the other closed state ("*To Rail*") connects one of these sections to Rail (with the other section isolated). An intermediate gate position ("*Isolated*") is normally provided where the operating handle has to be side shifted to complete the handle movement to the required position. The insulation level for the "Rail" terminal does not need to be for the full 1500V (since the "rail" is close to earth potential most of the time). The switch has 3 terminals.
   Symbol:



   d) *Sectioning* – This switch can connect its common terminal to either of 2 sections, and so has 2 "closed" states as well as the "open" state. It's similar in configuration to the Combined Isolating / Rail-Connecting switch (above), however all terminals need to be insulated for 1500V. The switch has 3 terminals.
   Symbol:



2. ***Switch Operating Mechanism*** – This is the mechanical means used to operate the switch, from closed to open and vice versa. This includes:

   a) *Manually Operated* – A hand operated lever changes the switch status. This is by far the most common configuration. See *Figure 414*.

   b) *Motor Operated* – An electric motor provides the effort needed to change the switch status. This arrangement normally provides for both remote and local control of the switch. See *Figure 415*. Remotely isolating is okay, however, remotely *testing* that the section is "dead" before switching to rail-connect apparently still remains a problem to be resolved in Sydney's system.

3. ***Switch Rating*** – Switches exist in the OHW system with the following continuous ratings:

   a) 1,000 Amp (Only very old switches may have this low rating.)

   b) 2,000 Amp.

   c) 3,000 Amp (This is the standard rating these days – seen in *Figure 414*.)

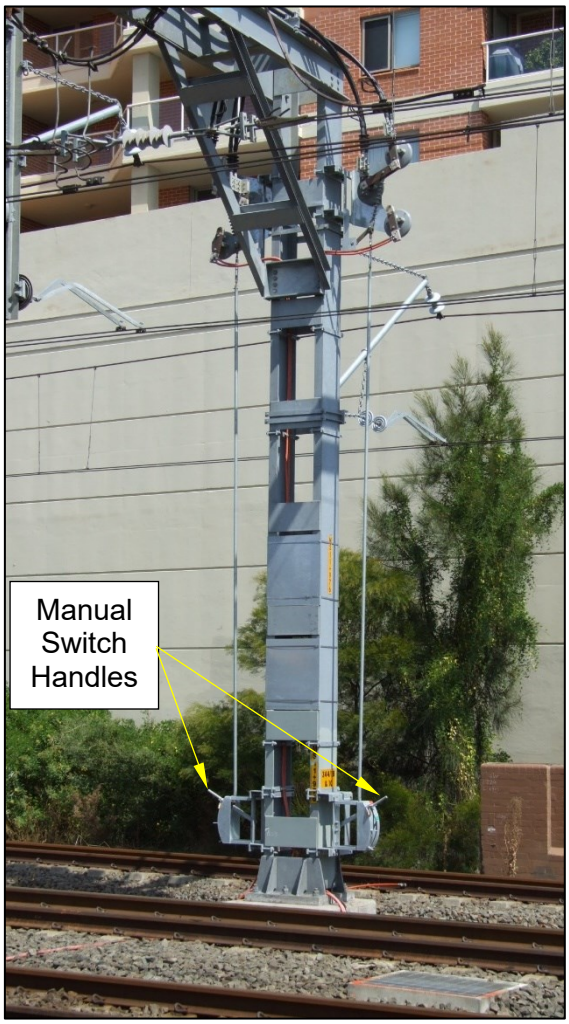


Figure 414 - Manually controlled switches

Figure 415 - Remotely controlled motorised switches

SWITCH TERMINALS

The current ART (Multi-Contact) type switch has silver-plated thick copper terminals which generally have a myriad of holes, much like "Swiss cheese" in appearance. Refer to *Figure 416*.

These holes are deliberately designed to accommodate either the standard U-Bolt clamping of aerial feeder wires (usually 270mm²), or connecting a cable lug (usually 400mm² cable) with 2 bolts.

Figure 416 - Special hole pattern on Switch terminal

The standard stainless steel U-bolt with gunmetal pads has a hole spacing of 44mm between legs, whereas the cable lug has 50mm hole spacing between the pair of bolts that fasten it to the copper plate. (It's a pity they're not the same dimension.)

So, this plate accommodates the 4 U-bolts for the twin 270mm² aerial connection, as well as the 4 SS bolts needed to clamp a pair of 400mm² cable lugs (but not at the same time).

In practice, the cable feeder can come from different directions, as can the aerial feeder wire. So, the grouping of holes takes all this into account by providing a versatile configuration – they can come in at 0°, 90°, 180° and 270° in relation to the long direction of the plate.

RAIL-CONNECT FACILITY

In the late 1980s or early 1990s there was a push, in certain crucial areas of the network, to provide facilities that could reduce the time it takes to render the rail environment safer, especially to allow emergency services to quickly deal with a train-related problem in that area.

The rail environment is fraught with risks, but the ability to quickly isolate the electricity from the OHW was no doubt seen as a critical step to help make the area safe. But this also required the OHW to be electrically shorted-out to the track (i.e. rail-connected), in order to have a much reduced possibility of the OHW livening up.

The risk was that, even if the 1500V was removed from an electrical section of OHW ("isolated"), it was still possible that a train in a nearby live section could inadvertently venture into an overlap at the start of the dead section, and then the pantograph bridging this overlap out would liven the isolated OHW and create a hazard to any workers on the OHW in that electrical section (which may be hundreds or even thousands of metres away). However, if the isolated section was also rail-connected, then the DCCB protection at nearby S/S and/or S/H should trip the supply if the above scenario played out, and this would minimise the chance of someone receiving a significant electric shock from the OHW.

Ideally the rail-connections should be established at any potential source of livening the OHW. This could mean at both ends of the isolated section, and also any other rail lines coming into the isolated area that may potentially jeopardise the OHW safe work area. Note well – Refer to the current Standards for the approach to be adopted.

Anyway, the ability to quickly rail-connect a section of OHW can be very convenient. (The use of portable rail-connecting cable is a possibility, but it has its own hazards.)

The typical wire size used to connect the switch to rail is 95mm² multi-stranded flexible copper cable. If the length of cable run is long, then additional cables may need to be run in

parallel, or a larger cable size can be used. These days 120mm² multi-stranded copper cable is becoming more popular.

In cases of switch banks, often a cable is daisy-chained between successive switch "rail" terminals, then a separate cable is connected from first to last to provide some redundancy and also to lower the electrical resistance of the circuit. A separate cable then connects from this circuit to traction rail or impedance bond (this decision must be made by signals staff in each case – see below).

TRACTION RAIL

When connecting the OHW to rail, either as a temporary rail-connection or as a permanent one (such as at a rail-connecting switch), it is extremely important to know which rail of a particular track is to be used to make the actual "rail connection".

The Signals discipline must always be consulted in this regard, so that they can advise where and how best to make this important connection.

The concern (as I understand it) is that some types of signal circuit technology can be adversely affected if the OHW is connected to the wrong rail of a track, and this can have serious safety implications.

The rail that can be connected to the OHW is termed the "traction rail".

I think other (modern) signalling technology, used in Sydney, is immune to this problem, but only the signals discipline can advise in this regard.

A potential hazard with connecting to one particular "traction rail" of a track occurs if part of that track is unknowingly taken up or somehow disconnected (i.e. not electrically continuous) further towards the substation, or if certain *impedance bonds* are removed during works on the rail infrastructure. Both activities can disconnect this local rail connection from substation negative, with possible adverse consequences. The exact scope of works needs to be understood and controlled to avoid this situation.

In certain junction areas with lots of converging tracks, sometimes signals discipline may advise to connect to their track impedance bond, which may inter-connect many tracks. For example, the permanent 7-switch arrangement at North Sydney had its common *rail-connection* cable connected to their local impedance bond, which made the design of the switch arrangement more convenient. See *Figure 418*.

My understanding of Sydney's Signalling system is very limited, so I will say no more – talk to the experts in Signalling.

SWITCH PAIRS

A sectionable overlap is an obvious place to provide electrical sectioning to the OHW. Here a *sectioning switch* can be used to conveniently join or isolate the 2 established electrical sections, rather than manually connecting or disconnecting the feeder jumpers.

But what if there's the need to rail connect one or both electrical sections?

A *sectioning and rail-connecting switch* can be used in this situation, but it can only rail-connect one electrical section (not both) – either the Sydney section or the country section.

If there's a requirement to rail-connect both the Sydney and the country sections, then 2 isolating and rail-connecting switches are needed – forming a type of "*switch-pair*". See the schematic in *Figure 417*.

In this case the "common" terminal (where the blade pivots) of one switch connects to the Sydney section and the common terminal of the other switch connects to the country section. The top terminals of the 2 switches are connected together, and the 2 bottom "rail" terminals are also connected together, and these are then connected to the traction rail by 95mm² or preferably 120mm² copper cable.

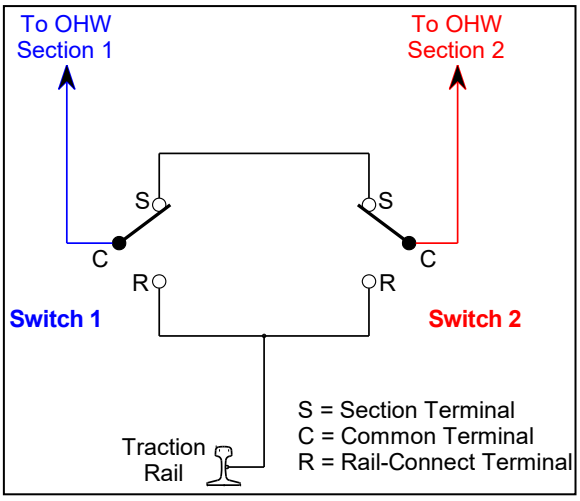


Figure 417 - Schematic of Switch Pair for Rail-Connections

So, to isolate and rail-connect the OHW for both electrical sections, 2 separate switch operations (Switch 1 and Switch 2) are needed, and this makes for a very convenient and flexible arrangement.

SWITCH BANKS

Switches are most commonly installed on masts or portal legs, where aerial feeders can conveniently connect from switch to the adjacent OHW catenary (and contact) with 3m or so of aerial twin feeder wire for each OHW connection.

A switch is often installed at one end of the overlap bay in a switched overlap. Here, the aerial feeders can directly connect to both of the electrical sections involved (often supported part way by gallows fittings), making it quite an efficient arrangement.

However, where a greater number of OHW sections need to be switched, then often this is best handled by installing several switches together and mounted on a common structure – a "Switch Bank" is formed. And the structure can be independent from other OHW structures.

A number of instances of switch banks exist throughout the electrified network, and the number is increasing. This is due in part to their convenience, when the need to switch several different local electrical sections is involved. Importantly, the switches can save time.

A good example is at North Sydney – *Figure 418* – where there's a bank of 7 manually-operated switches. These were designed and installed around 2012 to allow the convenient and quick isolation and rail-connecting of the several local electrical sections.

Figure 418 - 7-Switch bank at North Sydney

It's in an area where the 4 North Sydney Station tracks eventually converge into the normal 2 tracks that then head south along the viaduct to Milsons Point

Station, then over the Sydney Harbour Bridge. It is a highly visible area, and one that's crucial to the network, so any problems need to be dealt with quickly.

The 7-switch arrangement gives the benefits of sectioning flexibility and speed of operation (once someone's there to operate them). In this way, any urgent work on the OHW, or other train related emergencies requiring power off, can take place more rapidly.

This arrangement has a common, long equipotential mat which is bonded to the common steel frame on which all switch handles are mounted. The "rail-connected" terminal of each switch is connected to a local signal impedance bond, which has distributed connections to tracks (the configuration was suggested and agreed by Signal design as being the most appropriate way to rail-connect in this complicated multi-track area).

Figure 419 shows a bank of 8 switches and associated feeding being constructed at Chatswood in about 2005. The bank of 8 switches is on the left side of the photo, with operating handles installed on a nearby vehicle access ramp (further to the left). Workers were installing the 1500V cables from the switches across the portal bridge to the various "cable-to-aerial terminations" located above the relevant track (all 4 tracks were connected from this location).

Figure 419 - 8-Switch bank arrangement at Chatswood (being installed)

This switch bank was built for the Chatswood Interface Project as part of the (then new) Epping to Chatswood Rail Project (which was mostly inside 2 single-track tunnels located directly behind where this photo was taken).

The switches were required to provide main line electrical sectioning (and rail-connecting) flexibility in case of problems on the rather complicated 4-track configuration, which included 6 turnouts in a relatively short area between this switch arrangement and Chatswood Station less than 500m away.

Half the number of 1500V feeder cables went across the portal bridge, and the other half headed across another "bridge" connecting to the RES (Railway Enclosed Structure – in the background), to feed to the OHW on the remote side of each of the 4 main line Type 6 section insulators (one per track).

The portal itself is a busy structure – not only does it support the OHW and switch feeding to it, but it also has main line tension regulators installed on each leg.

This switching bank arrangement was quite a difficult thing to design, and I guess what's unique is that, due to the limited space, the 8 operating handles are located above the inclined access ramp. This resulted in a rather long common equipotential mat, located on the surface of the incline. It was a convenient location, and it works. Vehicular on-track access is also provided here, with access gates just outside the left side of the photo for access prevention.

Aside: The 2 centre tracks which head down the tunnel are now dedicated to the new driverless "Metro" line out to Rouse Hill (as from 2019). No doubt this switch arrangement has since been reconfigured to suit the new independent train operations now.

REMOTELY CONTROLLED MOTORISED SWITCHES

Remote control of switches adds convenience and flexibility. They can usually be controlled from a distance through the SCADA system at the Electrical Operating Centre, or at the switch itself (either electrically with the push of buttons in the local control cabinet, or manually with an appropriate manual operating handle there). See *Figure 415* further back. However, I think it still requires someone to "test dead" the OHW before finally closing the switch to the "rail" position.

Figure 420 gives an idea of the mechanism inside the control cabinet. Note the green "**OPEN**" and red "**CLOSE**" buttons at the top right-hand side, for local control of the switch.

Obviously, this type of switch requires a reliable power supply, to energize the motor which changes the switch to the desired position. It also requires a reliable communications path, normally back to the Electrical Operating Centre. If either of these 2 things fail, the switch can't operate remotely. In this case, someone has to go on site to manually operate the switch (in one way or another).

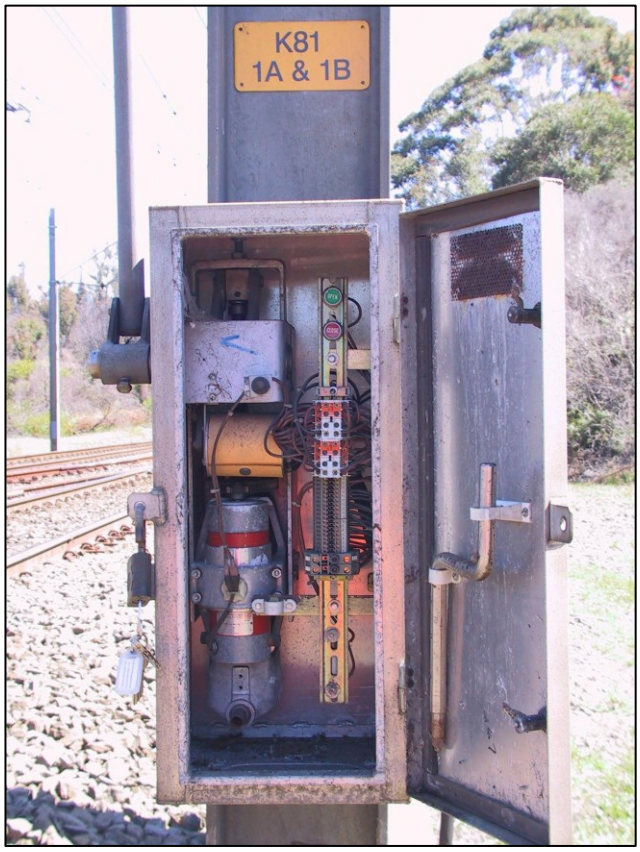


Figure 420 - Inside the control cabinet

There have been a few attempts to try to incorporate appropriate control technology in a remote switch which can automatically "test dead", and *rely* on this status to then allow the switch to close to rail. I'm not sure if this has been achieved in Sydney's system yet, but for a long time it remained a desirable thing to achieve (because of the need for someone to "test dead" on site, which can be time consuming).

If the switch "opens" while still drawing any significant train current, this can cause substantial arcing at the switch blade-to-terminal interface. Any significant arcing would damage the switch, and probably then prevent it from working properly when required, which will likely delay trains for quite some time. These switches are not designed for opening or closing under load, and it may cause the switch to become permanently damaged. (The large dc circuit breakers located inside substations and sectioning huts are designed to cope with "opening on load" on a regular basis.)

OTHER ASPECTS

Figure 421 shows a relatively old "Railway" type isolating and rail-connecting switch.

Figure 421 - Old "Railway" Isolating & Rail-Connecting Switch

It's fairly easy to see its configuration, so I use this as a case study below. (Other switches work in a similar way but may not be as obvious.)

This switch has 3 terminals:

- One terminal is mounted on the left post type insulator (which includes a set of contact fingers for accepting the blade),
- One terminal is mounted on the right-hand post type insulator (which holds the blade pivot), and
- One terminal, on the right side, is mounted on an insulation pad (which holds the other set of contact fingers). You can't see this insulation pad because it's only small.

The terminals on this switch are configured to clamp around a conductor (be it aerial wire to the OHW or 95mm² bared cable wire to rail connection). However, I think they can also accept a cable lug connection (?).

The sets of contact fingers each consist of 3 pairs of fingers that part as the switch blade passes through when making a solid electrical connection. In this way the fingers can apply a reasonably constant level of contact force onto the blade. A high contact force is necessary to reduce the finger-to-blade electrical resistance, which then minimises heating when heavy current is passed through the switch.

The right-hand post type insulator supports the switch blade pivot. Its terminal can feed to either the adjacent electrical section (as shown), or the blade can be rotated to connect to the fingers on the right hand side, which has a 95mm² copper cable connection to rail. This right-hand terminal should be isolated from the switch frame, but its insulation level doesn't need to be for 1500V, since rail volts are closer to earth potential. (The track rails must not be short circuited to earth, thus the need for some small level of insulation.)

The switch is operated by a white fibreglass-insulated rod (which I think used to be made of painted wood in the old days). The rod moves up to connect the electrical sections, and down to rail-connect the section fed at the switch pivot terminal.

This particular switch was wired with a single 270mm² copper aerial feed to the 2 terminals located on post type insulators, and these fed to each side of a section insulator above the track. These days the aerial feeds would consist of *twin* copper feeder wires (normally 270mm²) to each electrical section. This is done:

- To help reduce overall electrical resistance,
- To provide a level of redundancy should one wire become damaged or develop a high resistance connection at switch or OHW connection, but mainly,
- To ensure that the wires don't overheat if and when passing the huge electrical train currents demanded these days.

When rotating the blade to a new position, the switch is designed to always isolate the current connection first, then it can connect to the next terminal. In this way there can never be an electrical connection to all 3 terminals at the same time. This is important as it may otherwise

cause a short-circuit (1500V to rail) and, in doing so, trip the electrical protection (DCCB), and may also do some other damage.

If the blade was to be rotated half way, this would isolate the electrical sections without also being rail-connected. To be properly isolated, there should be about 150mm electrical clearance from the ends of the blade to their respective nearby sets of fingers.

I understand the old railway switches came in current ratings of 1,000amp, 2,000amp and 3,000amp, and this last rating was particularly onerous on the switch.

Figure 422 shows a switch installed in 2010, connecting across a Type 6 SI, at Epping Turnback Road. It allows this track to be readily isolating from the network and rail-connected.

The switch blade pivots on the centre insulator, and this pivot connects to the Turnback Road (left side). So, in the upper position, this blade connects to the main OHW (right side), and in the lower position it connects the OHW for this short track run to rail as required.

Figure 422 - Recent Isolating & Rail-Connecting Switch

Note the use of the single gallows fitting that supports both the aerial feeders. This fitting takes most of the strain off the switch arrangement, minimising switch contact alignment problems when the regulated OHW moves with temperature.

There's no in-span feeder to the contact wires, probably because it's a single dead-end track, or they may have been installed after the photo was taken (?).

3.7.0.5 Design Notes

Frame Stiffness

A switch frame holding all its various components needs to be extremely stiff, so that the rotating blade doesn't go out of alignment when it moves and approaches the 1 or 2 sets of contact fingers.

Misalignment can occur if the aerial feeders to the OHW pull at the switch terminal/s in an oblique direction with a high load. While this can be compensated for, any *change* in the direction of the aerial feeder load, or the load itself, can cause further misalignment problems. For instance, the load direction can change due to the regulated wires moving longitudinally with temperature.

The installation of gallows support fittings can be a benefit in this regard, as they can help support and control the aerial feeder load and any changes in the direction of that load. This is especially true if the aerial feeder lengths are long (greater than about 3m) and the gallows fitting is able to support the wires about midway (1.5m or so).

WIPING CONTACTS

As with most switches that carry significant current, the actual contact connection should involve some degree of "wiping" the contacts in the process of the blades closing and opening.

In this way, the actual surfaces making contact remain clean and oxides don't build up, which helps keep the contact resistance low, and lessens the chance of the contacts "welding" in position when passing lots of current.

CONTACT FINGERS

One of the difficult things with a heavy current switch, when moving to the closed state, is that there are 2 opposing requirements:

- The final connection needs to offer a very low resistance, and to achieve this usually requires a large surface contact area and a *large amount of force* between blade and connecting terminal to keep the contact resistance very low.
- The sliding action of the contacts should not offer excessive friction, otherwise the contacts will quickly wear out and need renewal. This means having the *bare minimum force* applied to the contacts to make the connection (even with lubrication). Also, the relatively soft silver metal can be quickly abraded when under excessive frictional contact.

The actual switch designer obviously needs to compromise on the above in order to come up with a suitable design that achieves the high current rating but without wearing the contacts out too quickly. Installing contact fingers can help in this regard.

Contact fingers are typically installed where the switch blade connects with the terminal when it closes. Depending on the design, the fingers can be located on the terminal or on the blade itself.

These fingers are spring-loaded for readily accepting the sliding connection, while providing a high contact pressure when closed. High contact pressure leads to a low resistance joint which is desirable when passing extremely high currents for relatively long periods of time. This in turn means less temperature rise when heavy current passes through the connection.

The fingers and also the end of the blade or terminal that connects to them, would usually be silver or silver-coated copper for a low electrical resistance connection (and readily able to conduct any heat away).

However, the fingers need to be regularly greased, otherwise the friction when closing and opening the switch would rapidly wear the fingers and/or the blade contacting surfaces. The grease also helps prevent oxidation of the silver, and of course, it should help reduce the effort needed to change switch position – open to close and vice-versa.

LUBRICATION OF SWITCH BLADE PIVOT & FINGERS

Greasing the contacts can help keep the contacts clean by slowing any oxidation.

But the problem with lubrication (and this applies to most equipment in the OHW system) is that, unless the lubricant is somehow sealed from the outside environment, any dust, sand, grit, etc. that's blown onto the lubricant, can stick to it and then make its way to the area of action and actually lead to abrasive wear (like sandpaper) of the silver contact surfaces. It is to their detriment, and ultimately reduces the life of the switch contact mechanism. This is the exact opposite of what's intended, i.e. reduced friction and wear.

In any case, these areas need to be regularly lubricated.

Ideally the old grease should be removed (which takes away any accumulated dust particles, etc.), before the new grease is applied. And this should be done regularly (depending on the environment and frequency of operation) to avoid wear problems and premature replacement.

There may be other strategies to help cope with this situation, so look to the Standards for guidance.

PASSING CURRENT THROUGH THE PIVOT

One of the terminals has a pivot connection, to allow the switch blade to rotate to its various positions, but this can pose a problem to the switch manufacturer.

The terminal with the pivot needs a good electrical connection from its terminal to the blade, as this has to be capable of carrying the load current of thousands of amps. However, the connection must also allow the contact interface (from terminal to blade) to move (rotate) as the switch is operated.

The contact interface needs to therefore have a low electrical resistance, and this normally achieved by designing it with a large contact surface area and a high contact pressure.

A high contact pressure can be a problem, because the blade needs to move relatively freely, otherwise the operator below may experience difficulty when manually shifting the blade to another switch position.

Greasing the contact surface of the pivot can help, but this tends to be squeezed out over time, leaving a silver-to-silver/copper friction joint. So, greasing would need to be done regularly.

The sheer mass of the copper/silver terminal and blade can help dissipate the heat generated when passing heavy current, but ideally a lower electrical resistance is the key to the success of a switch.

The design of this pivot point is obviously crucial, and this is where the switch manufacturer's expertise can bring about an optimum practical solution to the problem.

Fortunately, for most normal situations the pivot terminal shouldn't need to carry the heavy current *and* move at the same time.

The alternative is to use *braided copper or silver wire* to carry the heavy current from terminal to blade, thus mostly bypassing the pivot point. This can be quite effective provided the braid doesn't fatigue over time, and provided it doesn't sag and eventually lead to electrical clearance issues.

OPERATING ROD FLEXIBILITY

The vertical distance of the operating rod, from the switch handle up to the switch itself, can be about 6m or so. This is extremely long and can cause the rod to flex if it isn't stiff enough.

Ideally the operating rod should have a relatively large diameter to provide suitable stiffness, but it should also be light in weight so the operator doesn't require too much effort when operating the rod in an upward direction (and controlling its lowering downwards can also be an issue).

If the rod flexes too much, it may simply bow out instead of moving the blade, which can be a serious problem.

Some past switch arrangements had a 2-piece operating rod with a pivot located about half way up. This helped ensure flexing of the rod was kept to a minimum, but the pivot mechanism added slightly to the weight that needed to be pushed up when operating the switch.

Other switch arrangements simply had a guide installed half way up, to help control any sideways movement.

BREAKING DC CURRENT UNDER LOAD

These OHW switches are not designed to interrupt dc current, and especially not the level of heavy current flowing in an OHW system when supplying trains.

Purpose-designed dc circuit breakers in substations and sectioning huts are used to break any heavy current in the OHW circuit. So, if there's any doubt, these should ideally be used to open the circuit before the local switch is operated.

Figure 423 shows how much damage can take place to the contacts if significant current is allowed to pass when opening the blades of a switch to isolate supply.

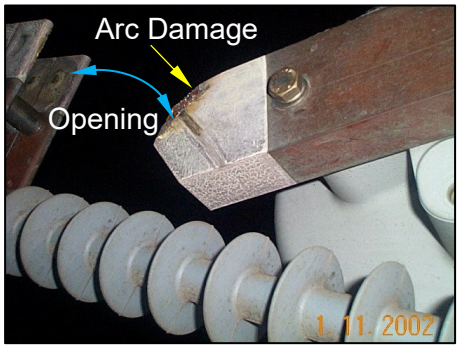


Figure 423 - Contact damage from arcing

Obviously these switches won't last long if they sustain this type of damage from time to time.

EQUIPOTENTIAL OPERATOR'S PLATFORM

When operating a switch by its handle (some 5m or so below the switch), there may be a slightly elevated chance of an electrical fault somehow occurring as the switch blade mechanism moves. If an electrical fault were to happen, the operator below needs to remain protected against any chance of electrical shock should current somehow transfer down to ground.

A steel "equipotential platform" (or "equipotential mat") is intended to prevent such a hazard. It is located at the base of the switch mast where the operator stands to operate the switch handle.

A standard arrangement was developed and signed off in 2008 to show how to configure an appropriate equipotential mat for 1500V switches – see *Figure 424*.

The switch handle should be electrically connected to this mat with a heavy gauge copper wire. This wire should not be part of any earthing circuit (so no fault current should ever pass through it).

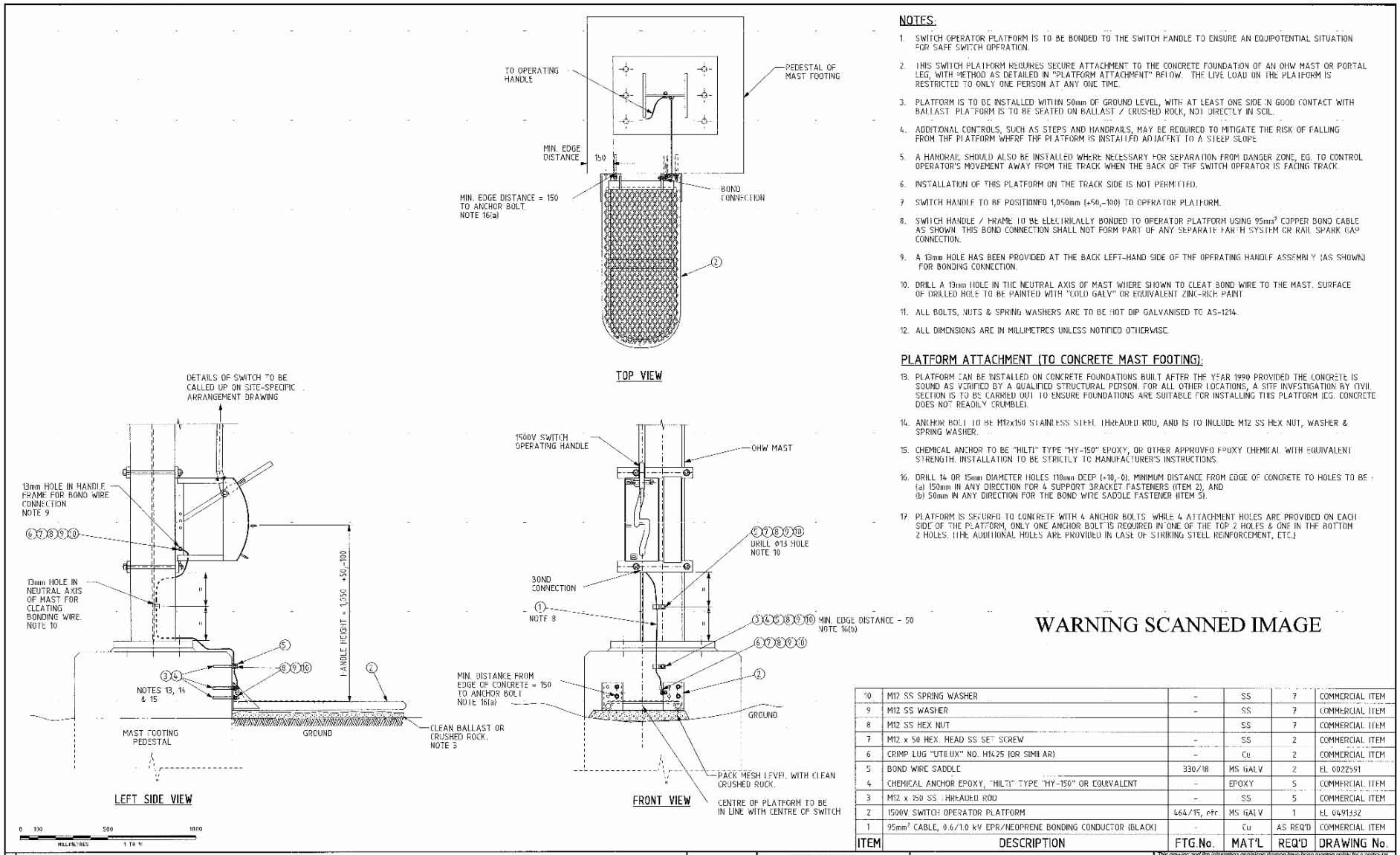
With this type of connection there should be no *step potential* or *touch potential* issues for an operator, between handle and mat.

"Step potential" is the term used to describe the situation where a voltage appears between the feet of a standing person. (Having rubber-sole boots is an added line of defence against such a hazard.)

"Touch potential" refers to a voltage appearing between hands or between hand and other part of body.

With most electrical systems, under certain circumstances, any touch potential or step potential – if high enough and for long enough – can cause harm to a person. (There are graphs available that show the risk of electrocution as a function of step/touch potential and duration.)

This operator's platform configuration is intended to avoid both step and touch potential issues.


TO OPERATING HANDLE
PEDESTAL OF MAST FOOTING
MIN. EDGE DISTANCE
150
MIN. EDGE DISTANCE = 150 TO ANCHOR BOLT NOTE 16(a)
BOND CONNECTION
TOP VIEW
DETAILS OF SWITCH TO BE CALLED UP ON SITE-SPECIFIC ARRANGEMENT DRAWING
13mm HOLE IN HANDLE FRAME FOR BOND WIRE CONNECTION NOTE 9
13mm HOLE IN NEUTRAL AXIS OF MAST FOR CLEATING BONDING WIRE. NOTE 10
HANDLE HEIGHT = 1,050 +50,-100
NOTES 13, 14 & 15
MAST FOOTING PEDESTAL
GROUND
CLEAN BALLAST OR CRUSHED ROCK. NOTE 5
LEFT SIDE VIEW
1500V SWITCH OPERATING HANDLE
OHW MAST
DRILL Φ13 HOLE NOTE 10
BOND CONNECTION
NOTE 8
MIN. EDGE DISTANCE = 50 NOTE 16(b)
MIN. DISTANCE FROM EDGE OF CONCRETE = 150 TO ANCHOR BOLT NOTE 16(a)
GROUND
PACK MESH LEVEL WITH CLEAN CRUSHED ROCK.
CENTRE OF PLATFORM TO BE IN LINE WITH CENTRE OF SWITCH
FRONT VIEW
0 100 500 1000
MILLIMETRES 1 TO 10

NOTES:

1. SWITCH OPERATOR PLATFORM IS TO BE BONDED TO THE SWITCH HANDLE TO ENSURE AN EQUIPOTENTIAL SITUATION FOR SAFE SWITCH OPERATION.
2. THIS SWITCH PLATFORM REQUIRES SECURE ATTACHMENT TO THE CONCRETE FOUNDATION OF AN OHW MAST OR PORTAL LEG, WITH METHOD AS DETAILED IN "PLATFORM ATTACHMENT" BELOW. THE LIVE LOAD ON THE PLATFORM IS RESTRICTED TO ONLY ONE PERSON AT ANY ONE TIME.
3. PLATFORM IS TO BE INSTALLED WITHIN 50mm OF GROUND LEVEL, WITH AT LEAST ONE SIDE IN GOOD CONTACT WITH BALLAST. PLATFORM IS TO BE SEATED ON BALLAST / CRUSHED ROCK, NOT DIRECTLY IN SOIL.
4. ADDITIONAL CONTROLS, SUCH AS STEPS AND HANDRAILS, MAY BE REQUIRED TO MITIGATE THE RISK OF FALLING FROM THE PLATFORM WHERE THE PLATFORM IS INSTALLED ADJACENT TO A STEEP SLOPE
5. A HANDRAIL SHOULD ALSO BE INSTALLED WHERE NECESSARY FOR SEPARATION FROM DANGER ZONE, EG. TO CONTROL OPERATOR'S MOVEMENT AWAY FROM THE TRACK WHEN THE BACK OF THE SWITCH OPERATOR IS FACING TRACK.
6. INSTALLATION OF THIS PLATFORM ON THE TRACK SIDE IS NOT PERMITTED.
7. SWITCH HANDLE TO BE POSITIONED 1,050mm (+50,-100) TO OPERATOR PLATFORM.
8. SWITCH HANDLE / FRAME TO BE ELECTRICALLY BONDED TO OPERATOR PLATFORM USING 95mm² COPPER BOND CABLE AS SHOWN. THIS BOND CONNECTION SHALL NOT FORM PART OF ANY SEPARATE EARTH SYSTEM OR RAIL SPARK GAP CONNECTION.
9. A 13mm HOLE HAS BEEN PROVIDED AT THE BACK LEFT-HAND SIDE OF THE OPERATING HANDLE ASSEMBLY (AS SHOWN) FOR BONDING CONNECTION.
10. DRILL A 13mm HOLE IN THE NEUTRAL AXIS OF MAST WHERE SHOWN TO CLEAT BOND WIRE TO THE MAST. SURFACE OF DRILLED HOLE TO BE PAINTED WITH "COLD GALV" OR EQUIVALENT ZINC-RICH PAINT.
11. ALL BOLTS, NUTS & SPRING WASHERS ARE TO BE HOT DIP GALVANISED TO AS-1214.
12. ALL DIMENSIONS ARE IN MILLIMETRES UNLESS NOTIFIED OTHERWISE.

PLATFORM ATTACHMENT (TO CONCRETE MAST FOOTING):

13. PLATFORM CAN BE INSTALLED ON CONCRETE FOUNDATIONS BUILT AFTER THE YEAR 1990 PROVIDED THE CONCRETE IS SOUND AS VERIFIED BY A QUALIFIED STRUCTURAL PERSON. FOR ALL OTHER LOCATIONS, A SITE INVESTIGATION BY CIVIL SECTION IS TO BE CARRIED OUT TO ENSURE FOUNDATIONS ARE SUITABLE FOR INSTALLING THIS PLATFORM (EG. CONCRETE DOES NOT READILY CRUMBLE).
14. ANCHOR BOLT TO BE M12x150 STAINLESS STEEL THREADED ROD, AND IS TO INCLUDE M12 SS HEX NUT, WASHER & SPRING WASHER.
15. CHEMICAL ANCHOR TO BE "HILTI" TYPE "HY-150" EPOXY, OR OTHER APPROVED EPOXY CHEMICAL WITH EQUIVALENT STRENGTH. INSTALLATION TO BE STRICTLY TO MANUFACTURER'S INSTRUCTIONS.
16. DRILL 14 OR 15mm DIAMETER HOLES 110mm DEEP (+10, 0). MINIMUM DISTANCE FROM EDGE OF CONCRETE TO HOLES TO BE :
    (a) 150mm IN ANY DIRECTION FOR 4 SUPPORT BRACKET FASTENERS (ITEM 2), AND
    (b) 50mm IN ANY DIRECTION FOR THE BOND WIRE SADDLE FASTENER (ITEM 5).
17. PLATFORM IS SECURED TO CONCRETE WITH 4 ANCHOR BOLTS. WHILE 4 ATTACHMENT HOLES ARE PROVIDED ON EACH SIDE OF THE PLATFORM, ONLY ONE ANCHOR BOLT IS REQUIRED IN ONE OF THE TOP 2 HOLES & ONE IN THE BOTTOM 2 HOLES. (THE ADDITIONAL HOLES ARE PROVIDED IN CASE OF STRIKING STEEL REINFORCEMENT, ETC.)

WARNING SCANNED IMAGE

ITEM	DESCRIPTION	FTG.No.	MAT'L	REQ'D	DRAWING No.
10	M12 SS SPRING WASHER	-	SS	7	COMMERCIAL ITEM
9	M12 SS WASHER	-	SS	7	COMMERCIAL ITEM
8	M12 SS HEX NUT		SS	7	COMMERCIAL ITEM
7	M12 x 50 HEX. HEAD SS SET SCREW	-	SS	2	COMMERCIAL ITEM
6	CRIMP LUG "UTELUX" NO. H1425 (OR SIMILAR)	-	Cu	2	COMMERCIAL ITEM
5	BOND WIRE SADDLE	330/18	MS GALV	2	EL 0022591
4	CHEMICAL ANCHOR EPOXY, "HILTI" TYPE "HY-150" OR EQUIVALENT	-	EPOXY	5	COMMERCIAL ITEM
3	M12 x 150 SS THREADED ROD	-	SS	5	COMMERCIAL ITEM
2	1500V SWITCH OPERATOR PLATFORM	464/15, etc.	MS GALV	1	EL 0491332
1	95mm² CABLE, 0.6/1.0 kV EPR/NEOPRENE BONDING CONDUCTOR (BLACK)	-	Cu	AS REQ'D	COMMERCIAL ITEM

A ORIGINAL ISSUE
B ALTERNATIVE ARRANGEMENT INCLUDED, REFERENCE DRAWINGS" DES: K.CHONG DRN: A.TYRO CHK: M.HOOK 3/10/08

SCALES: 1:10

CAD DRAWING

REFERENCE DRAWINGS
EL 0491332 - 1500V SWITCH OPERATOR PLATFORM (DETAILS)
EL 0195635 - ALTERNATIVE 1500V SWITCH OPERATOR PLATFORM ARRANGEMENT

RailCorp
ASSET MANAGEMENT GROUP
Engineering Standards & Services Division
ELECTRICAL SERVICES SECTION

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APPROVED M.HOOK 12/08/2008

RailCorp Design accepted for use by RailCorp M.HOOK 12/08/2008

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GENERAL
RAILWAYS OVERHEAD WIRING
1500V SWITCH OPERATOR PLATFORM
ARRANGEMENT ©
FILE No. 0491331 A .DLOGN SHEET 1 OF 1 A1
STATUS: CURRENT
EL 0491331 B

Figure 424 - Typical Switch Operating Handle & Mat arrangement on OHW Mast

DESIGN OF SWITCHING / FEEDING ARRANGEMENTS

Switching (and feeding) arrangements will likely include the following practical aspects:

1. *Switch*. Type and make of switch (isolating, rail-connecting, isolating & rail-connecting), 3,000Amp, etc. Including the switch operating handle mechanism.
2. *1500V Cable* and *Cable Support* (if cable is used to connect switch).
3. *Cable-to-Aerial Termination* (if cable fed). This includes surge protection of the cable.
4. *Aerial Feeder*. Feed to the OHW conductors.
5. *Aerial Feeder Support* (*Gallows*). Additional support of the aerial feeder wires on their way to the OHW connection point, so as to not overstress the switch (which may otherwise put it out of alignment) and gain suitable electrical clearances to earth and next electrical section.
6. *OHW Connection*. This is normally done to the tail of the catenary or a catenary feeding loop, with additional in-span feeder connections to the contact wire/s.
7. *Switch Operators Platform*. Including the equipotential connection from operator's handle to operator's platform.
8. *Earthing*. This is a specialty area, so seek Standards advice. Earthing is needed to divert lightning surges effectively to ground (and away from other equipment), or to provide other safety requirements.
9. *Spark Gap*. This is a specialty area, so seek Standards advice. With a spark gap installed, if the structure supporting the switch/feeding livens up for whatever reason, the spark gap shorts out and connects the structure to rail, likely causing the electrical protection to operate. But the spark gap may be more prone to "shorting out" here.
10. *Access Prevention*. In certain situations, this may be needed to prevent people gaining access to electrical hazard areas or to the switch structure itself.

CRIMP LUG CONNECTION OF HDBC WIRE

Apparently, the high pressure crimping of a copper lug onto a *hard-drawn bare copper* (HDBC) conductor is *not advisable*.

There had been attempts to introduce this practice in recent years, mainly because it's apparently easy and quicker (and cheaper?) to make the connection, rather than to use the more cumbersome and time-consuming (but approved, and effective) way of using U-bolts connections with their heavy copper pads. I'm talking specifically of the termination of 270mm² hard-drawn bare copper wire into a long-sleeved lug.

As I understand it, for an effective electrical connection to take place with a crimp lug, both the copper wire and the copper crimp lug sleeve (which passes over this wire), should be made of relatively soft (annealed) copper. In this way, when the huge crimping forces are applied to the outside of the sleeve, both the sleeve and most (if not all) copper strands inside the sleeve get squeezed and deform under the pressure. In doing so, both the crimp and the affected copper strands get work-hardened to provide a solid mechanical and electrical connection. If you were to cut through the crimped sleeve you should see a virtual solid mass of copper, with little space between strands (and maybe no signs of such strands). This makes an effective and robust electrical connection, and should exhibit minimal electrical resistance.

However, hard-drawn bare copper strands are not soft – they're close to bronze in terms of hardness.

I had discussed this crimping matter with a senior engineer from a HV switch manufacturer, who confirmed that crimp lug connections to HDBC wire should be absolutely avoided.

I guess my concern about crimping the soft copper sleeve onto the hard copper strands is mostly to do with the high joint stresses placed on this interface by the dynamic nature of the (270mm²) aerial feeder wire heading out to the OHW. If this lug is solidly connected (bolted) to a rigid terminal on a switch, or to a cable-to-aerial termination 10mm thick copper plate, then the relative movement of the aerial feeder wire can place enormous stresses on the cable lug connection point, which is solidly fixed in position.

The aerial feeder wire movement, and subsequent enormous stresses on a connected lug, can come about from at least 2 mechanisms:

- The aerial feeder wire can move one way and then the other, several times daily if connected to regulated OHW, and
- The aerial feeder wire, with its reasonable length of 3m to 4m to the OHW, can also move about wildly with wind, particularly under gusty wind situations.

Because the individual hard-drawn strands are extremely hard, they may not totally deform under the applied crimp pressure, which would then leave spaces between the strands. The empty spaces can provide "wiggle room", and the frequent flexing of the connection (described above) can eventually cause the strands to begin to slide relative to each other when placed under such stresses and over a long time. If this slippage does begin to happen, then the mechanical connection is compromised and will likely become loose and ultimately lose its mechanical integrity. Even more importantly, its electrical integrity for passing heavy current (thousands of amps) will then be lost, and the wire/lug connection may suddenly part.

It's the sort of thing that may not work loose overnight, and it may be OK for a number of years, but in the long term the strands could work their way loose. It becomes an uncertainty, and one that may affect train running reliability. (In a sense, it's like metal fatigue, which can be insidious and take many years to make its presence known, but if it does happen, the results could be quite unpleasant.)

Also, a subsequent fatigue failure may occur in the area where the lug tube was initially squeezed flat during its manufacture. The forming process can weaken the lug in the zone where the round tube transitions to being flat (squashed). Any feeder wire that causes flexing movement on the lug may eventually fatigue the lug in this area of weakness. (Refer to *Figure 425* below for similar situation).

Also, by its very shape when compared to its sleeve (tube), the flat part of the lug has very little strength to resist movement caused by the stiff aerial feeder wire. This is a recipe for fatigue to occur if the conductor can move around at all (which it can).

Another aspect is that the standard practice of U-bolt connections allows for some degree of *adjustability* later on if needed, especially when maintaining the equipment – just loosen the U-bolts, clean the conductor, slide it along to its new position and fasten the U-bolts again.

This contrasts with the crimp lug connection approach, which will not allow any convenient adjustment – new crimps will need to be made once the old crimp lug is cut off (and wasted). As well, the remaining wire length may also be too short and more likely require new and longer aerial feeder wires to be installed.

Lastly, to adjust the U-bolts requires a spanner to loosen the connection, and a common torque wrench to retighten the U-bolts to the correct tension.

To recrimp requires the correct crimp lug (an incorrectly sized lug is not a forgiving beast), and also the special hydraulic or battery-powered crimp equipment fitted with the correct die.

Lug size, die size, die pressure, number of crimps and minimum spacing between crimps need to all be standardised and followed exactly, in order to reduce the risk of failure later in time. This is a big ask, bearing in mind the possible number of different conductor sizes that might be there, and not to mention the types of short cuts some people sometimes take.

So, there's a lot more *quality control* needed when making a new crimp, whereas the U-bolt approach is much more straightforward, and proven over many decades of use.

So in summary, the crimp lug connection of hard-drawn bare copper wire should be avoided, unless a lower level of reliability is accepted by the organisation.

It was also suggested that the solid *contact wire* could likewise be crimp-lugged. The sample provided had a long barrel (for a decent crimp), and this barrel was cut through about half-way with a hacksaw to show the inside connection – refer to *Figure 425*.

Again, the crimp connection may not be that effective in the long term, as described above. But more importantly, the compressed flat portion of the lug, when manufactured, becomes highly susceptible to fatigue, especially if the solid bar-like contact wire moves at all and stresses this connection every now and then.

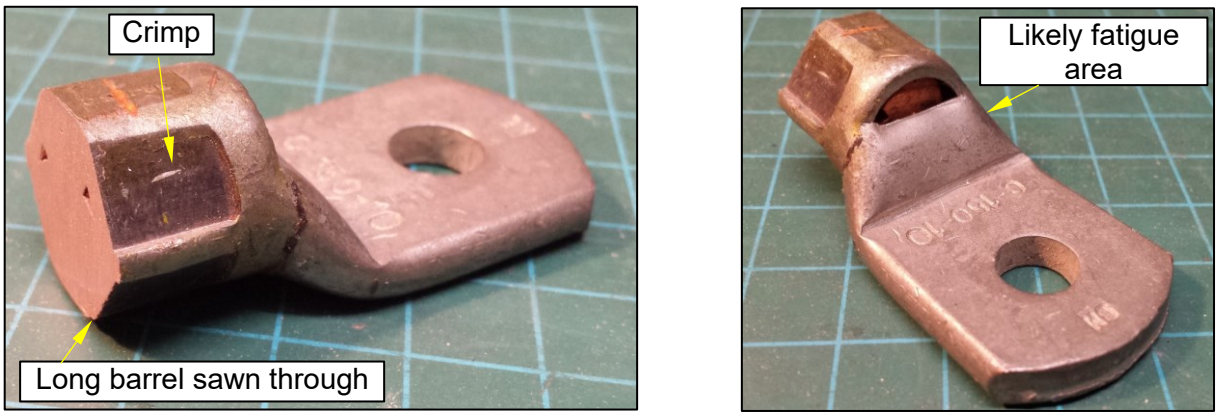


Figure 425 - Sample of suggested crimp lug connection to Contact wire (barrel cut through)

DIFFERENT SWITCHING SCENARIOS

Appendix "B" – Switching & Feeding Situations shows several switching scenarios in diagrammatic form.

3.7.0.6 Status (c. 2014)

N/A.

3.7.0.7 Reference

See *Table 36* for drawing reference.

3.7.1 "Railway" Switch

3.7.1.1 Description

There have been a number of switch arrangements developed since the early days of Sydney's electrification, and the old "Railway" switch, with its variants, is likely the result of this evolution.

These switches are still in the OHW system today, and they have proven to be quite reliable over the years. It is likely however, that very few, if any, are servicing OHW for the main lines.

They can be recognised by having standard post type insulators mounted *horizontally*, that hold the various terminal connections. For examples, see *Figure 426*, *Figure 430* and *Figure 431*.

Figure 426 - Railway Sectioning Switch

3.7.1.2 Function

See *Section 3.7.0.2*.

3.7.1.3 Typical Components

Being made by the railways over the decades, there are various parts of the switch that are, or were, in common use elsewhere in the system.

A good example is the post type insulator (fitting 452), which is a fairly compact but robust insulator that's able to withstand the type of jolting forces placed on it during operation as the switch is opened and closed. (Of course, this insulator is also used to support & register the OHW in many other configurations.)

The insulator is installed horizontally, to take full advantage of the corrugations on the underside of insulator and their ability to prevent heavy rain from forming continuous streams of water across the insulator, which may otherwise cause problems (e.g. larger leakage currents and increased likelihood of lightning flashover).

I think some of the clamps have also been borrowed from other OHW arrangements.

Other components such as switch blade, cast terminals, fingers, operating rod, handle mechanism, and associated hardware, have been specifically designed for the various Railway switches.

3.7.1.4 Configuration

Drawings of the various *railway switches* are available, including those with fitting numbers 431, 500, 500/1, 500/2, etc.

There are switches that connect one electrical section:

- To another electrical section (*Figure 427*),
- To another electrical section or rail (*Figure 428*),
- To either a 2nd or a 3rd electrical section, and
- To rail only (*Figure 429*).

Figure 427 - Railway Sectioning Switch

Some of the switches have been modified to suit certain situations. I had noticed one switch had all its 3 post type insulators raised by about 150mm to a higher level on the mounting plate – for whatever reason (which was not immediately obvious).

Figure 428 - Railway Isolating & Rail-Connecting Switch

Figure 429 - Railway Rail-Connecting Switch

Figure 430 is a CAD drawing of an isolating / rail-connecting switch, identifying where the terminals are and what they are for. Each terminal is intended for connecting 1 or 2 bare aerial feeder wires using a parallel clamp arrangement (which is part of the switch).

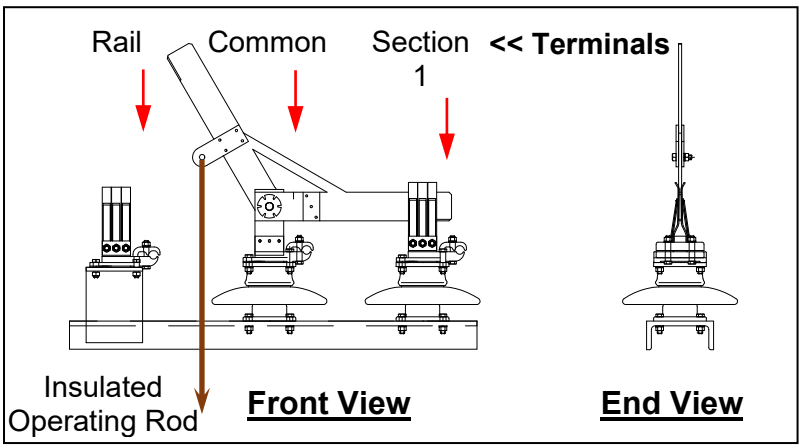


Figure 430 - "Railway" Isolating / Rail-Connecting Switch

Most likely the aerial feeder wire would be the 270mm² wire size, although I believe that these clamps can also take the 327mm² wire size as well (?).

Figure 431 is the isolating-only switch.

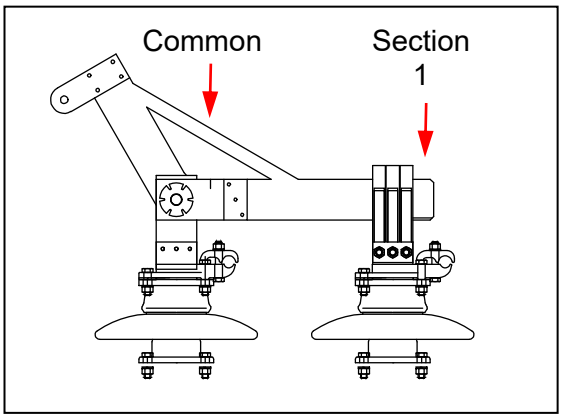


Figure 431 - "Railway" Isolating Switch

3.7.1.5 Design Notes

N/A.

3.7.1.6 Status (c. 2014)

These switches are no longer being installed in new OHW. Refer to Electrical Standards.

3.7.1.7 Reference

See *Table 36* for drawing reference.

3.7.2 BICC Switch

3.7.2.1 Description

I understand this switch was introduced and used primarily for the BICC Compound OHW system from Penrith to Bowenfels.

Unfortunately, I don't have a lot of information on this type of unique switch. Their current rating is unknown (to me), but is likely to be quite high (because they were suitable for powering the heavy electric freight trains up long, steep grades at the time).

Refer to *Figure 432* for an example.

Figure 432 - BICC Switch

3.7.2.2 Function

See *Section 3.7.0.2*.

3.7.2.3 Typical Components

This switch has the usual components – steel support frame, support and operating rod insulators, switch blade and accompanying fingers, contact terminals, lots of linkages, intermediate rod guide, operating handle mechanism, etc.

All the components seem to be unique to this arrangement.

3.7.2.4 Configuration

The switch shown in *Figure 432* – a "linked pair" – shows 2 side-by-side switches installed on a common frame and interlinked in a way that allows 3 positions:

- One switch (left) in closed position and the other (right) open (as shown in this figure),
- Vice versa, and
- Both switches in an intermediate isolating position.

Figure 433 shows a side view of such a switch-pair.

These switches are operated by 2 operating rods that both connect to opposite ends of a common link. This link then connects to both switches to operate them in a sequence as described in the dot points above.

My guess this that this configuration allows each operating rod that actions the switch, to take turns so as to be always in *tension* (not compression, which might otherwise cause the rods to bow too much over their long vertical length). A narrower operating rod diameter is the likely positive outcome of this approach.

Figure 433 - Side view of BICC Switch

Each switch has an upper and a lower (pivot) terminal, making 4 terminals in all. This allows for the variety of switch configurations, namely:

- Connecting to 2 electrical sections.
- Connecting to 2 electrical sections or 1 of these sections to rail (as in *Figure 432* and also in *Figure 434*).
- It looks like it could also connect to 3 electrical sections, maybe (?).

Figure 434 - BICC Switch & Operating Handle mechanism

3.7.2.5 Design Notes

The insulators are unique to this equipment, so any damaged insulators may be difficult to find replacements for now.

I had noticed that the newer "ART (Multi-Contact)" style switch is now installed at various locations in this area. This may be because of lack of spares for the original switches, or due to excessive wear, or maybe some frames or other parts were heavily corroded, or are they were simply considered *life expired*. Maybe their current rating was not enough for modern trains – the newer switches are, after all, rated at 3,000 amps.

3.7.2.6 Status (c. 2014)

Refer to Electrical Standards.

3.7.2.7 Reference

See *Table 36* for drawing reference.

3.7.3 "Edward Keller" Switch

3.7.3.1 Description

I think this switch was introduced in the 1970s or early 1980s.

I'm not sure why it was introduced – maybe as a possible improvement on the existing "railway" switches at the time, or better current capacity, or better reliability or convenience?

They are distinguished by their tall and narrow post type insulators to support the blade and associated terminals. They also had "stingers" (or "whiskers") to help quickly extinguish any arc during opening.

Of all the different types of switches in the OHW system, this one seems to be the least obtrusive in the field, maybe because it uses slender insulators.

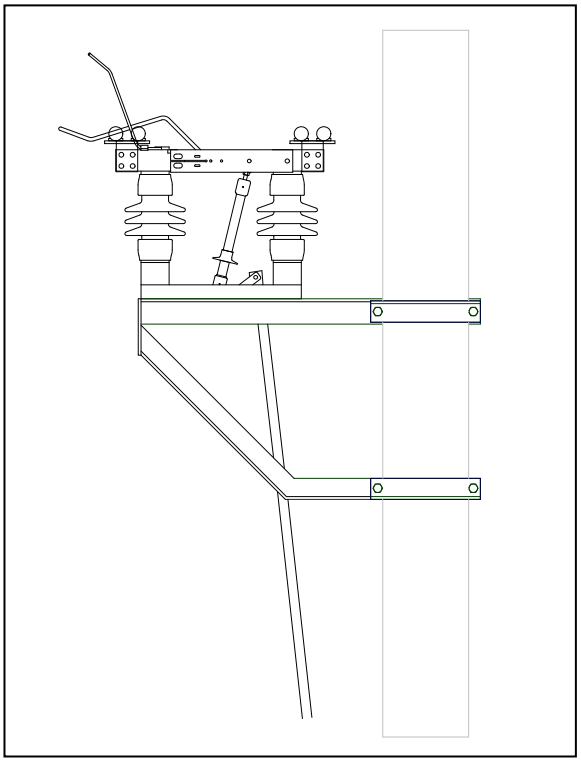


Figure 435 - "Edward Keller" Switch (Isolating only)

3.7.3.2 Function

See *Section 3.7.0.2*.

3.7.3.3 Typical Components

Components include:

- steel base,
- high conductivity switch terminals and blade,
- insulators for supporting the switch terminals and rotating blade mechanism,
- operating rod with associated pivots, etc.

However, each one also incorporates "stingers" (*whiskers*) that are small wires made from stiff, high melting-point metal and formed into a special shape that act as arcing horns – see *Figure 436*. One stinger is installed on the switch blade and the other is installed from the remote terminal. They are designed to help quickly extinguish any arc that may be established if current is drawn as the switch is opened, and this is done by lengthening the arc in an upward direction.

A thick copper plate, carefully bent into a right-angle, is bolted to each terminal of the original switch. See *Figure 436*. This then adapts to the standard OHW aerial feeder, or to 400mm² cables.

The aerial feed to this switch uses the 3 standard aerial feeder sizes of 165mm², 270mm² and 327mm², but predominantly 270mm² is used and in pairs. See *Figure 415* further back for a situation using aerial feeders.

So, the other end of the bent plate has holes with spacing to suit the standard OHW parallel feeder clamp U-bolt arrangements (from the 54/- series) for aerial feed, or a different hole spacing for cable termination. If used, the gunmetal pad from the feeder clamps is machined flat to ensure a good low resistance connection from clamp to angle plate.

3.7.3.4 Configuration

This switch was probably the first switch to have the stiff wire arcing horns that can help deal with an unintended arc if the switch was taking some small load current at the time of opening.

It also has an intermediate support pivot for the operating rod, located about half-way up the mast.

The operating rod connects to the switch blade using another pivot mechanism located near the base of the switch insulators. The other side of this pivot has a short insulated rod (with a single skirt to shed water) that connects to and operates the blade.

The additional switch pivot results in the switch blade opening upward – OPEN – when the operating rod is pull downward. So, the operator lifts the operating handle to CLOSE the switch, as depicted in *Figure 437*.

Figure 436 - Edward Keller Switch

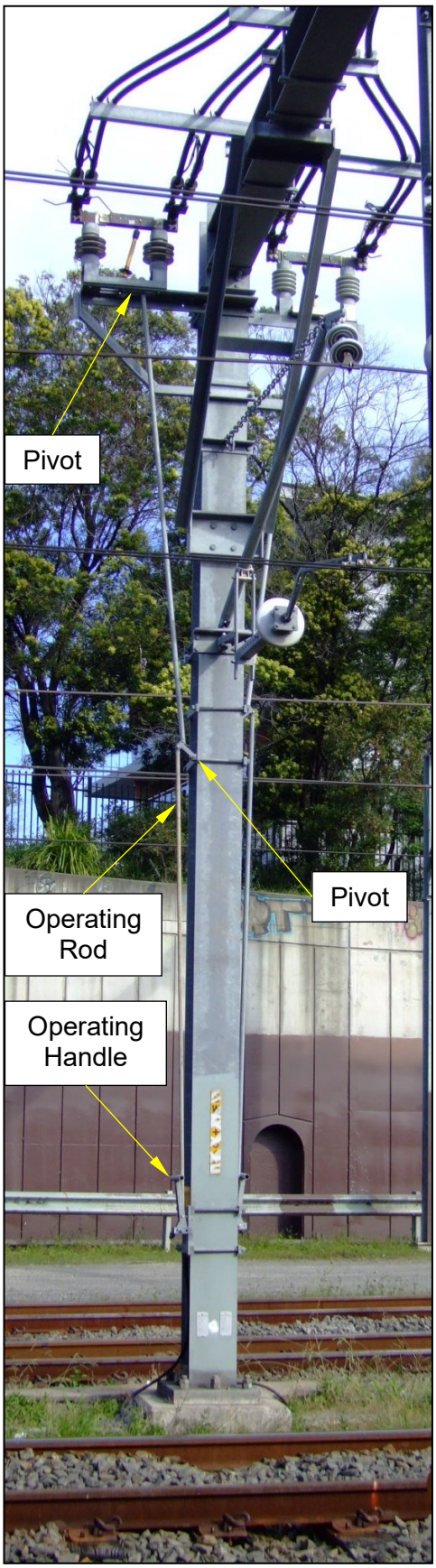


Figure 437 - EK Switch

I'm not aware that there is a combined sectioning / rail-connecting variant to this switch, which may have been a disadvantage of this arrangement. And the need for such a versatile switch was, at the time, becoming increasingly more important.

Having said that, installing 2 such switches side-by-side on either side of a mast may provide the isolating / rail-connecting facility (with 2 operating handles).

The terminals for this switch are situated such that the attached feeders can come from the left or the right side of the switch, when viewing the switch as shown in *Figure 438*. This is a

good outcome, as it minimises inventory (there's no left or right-hand switch versions to store) – contrast this with the ART / Multi-Contact switch (in the next section) which does have left and right-hand versions (doubling the inventory).

3.7.3.5 Design Notes

Design drawing K/87069 (EL0005425) shows the configuration of the motorised version of this switch installed on a mast. It also gives details of the arrangements needed for the conversion to manual operation.

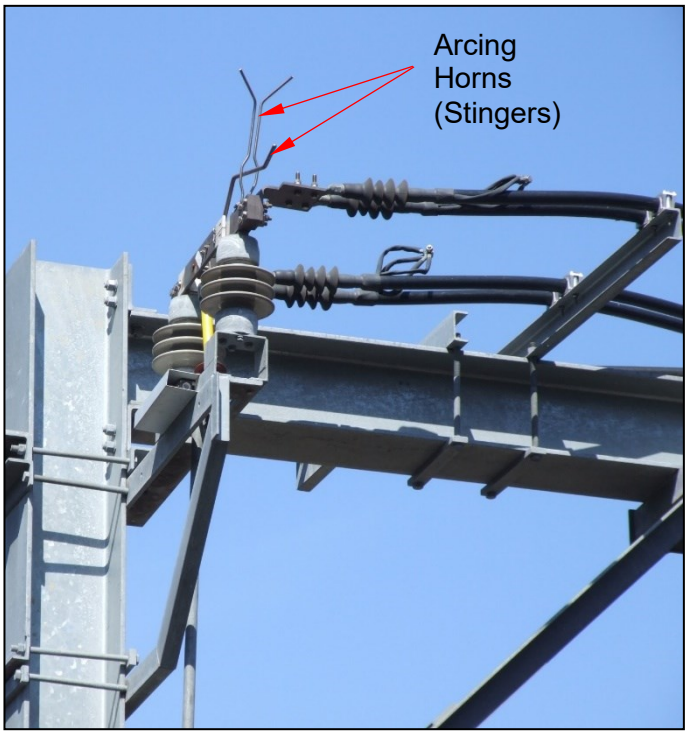


Figure 438 - Arcing horns on EK Switch

3.7.3.6 Status (c. 2014)

Refer to Electrical Standards.

3.7.3.7 Reference

See *Table 36* for drawing reference.

3.7.4 "ART" (Multi-Contact) Switch

3.7.4.1 Description

I understand these switches were developed by the Multi-Contact company for Sydney's system, as an alternative to the EK switch (which they also sold previously). They had a good local understanding of the functional requirements of the 1500V switch, and likely knew the need for some improvements and simplifications.

This style of switch was accepted for use in Sydney's OHW system after initial proof testing in the 1990s. These switches are now provided by Australian Rail Technology (ART).

The new switch arrangement was able to make use of the (then new) standard resin post type insulator (fitting 452/10) which, because of its incredible strength, has resulted in a relatively robust switch that appears to have proven itself over the time since its introduction.

Figure 439 - The ART Switch, ready for wiring

It's a 3,000amp switch, and is available in a number of alternative switch pole configurations to suit Sydney's electrified system. It's available in left-hand or right-hand versions to suit a particular situation (which is both good and unfortunate).

It is now likely the most common switch installed throughout the network, and it seems to also be the most physically obvious, due to the significant size of flat steel support plate installed vertically.

They are also used in the 1500V switch area of many substations and sectioning huts, to isolate and rail-connect the nearby OHW.

3.7.4.2 Function

See *Section 3.7.0.2*.

3.7.4.3 Typical Components

Various components include:
the steel base, switch terminals and blade, insulators for supporting the switch terminals and rotating blade mechanism, operating rod with associated pivots, etc.

3.7.4.4 Configuration

LEFT / RIGHT VERSIONS

Unlike previous switches which are symmetrical, the ART (Multi-Contact) switch has its terminals facing on one side or the other – the designer must choose.

So, there is a "Left-hand" version and a "Right-hand" version of the switch, and this doubles the number of possible variants that need to be specified when ordering.

This is one of the few disadvantages of this type of switch, and this has at various times led to either designing, ordering or trying to install the wrong switch at a particular location.

However, this aspect just needs to be properly managed. According to the design drawings, the manufacturer assumes the Left-hand version, and adds the suffix "R" to designate a Right-hand version of the switch.

OPERATING HANDLE

There are different switch operating handle mechanisms that are suited to the 4 *Types* of switches (described in *Variants* below):

- Isolating & Rail-Connecting,
- 2 Position,
- 2 Pole, and
- Rail-Connecting.

Where a switch has 3 distinct positions, there is a handle gate pattern shaped like a side-wise "Z", with a gate position at top, at middle and at bottom (corresponding to the 3 possible positions). See *Figure 440* for an example.

There is also a simpler gate pattern for the 2 position switches (closed or isolated).

So, the relative position of the guiding slot for the handle to move is different for all 4 main variants.

Figure 440 - ART Switch Operating Handle

VARIANTS

Table 38 lists the drawings of the 4 functional types of ART (Multi-Contact) switches, and each comes in a "Left-hand" and a "Right-hand" configuration, giving a total of 8 possible switch variants.

	Left-Hand		Right-Hand	
ART (Multi-Contact) Switch Type	**Fitting No.**	**Drawing No.**	**Fitting No.**	**Drawing No.**
a) Isolating & Rail-Connecting	502/1	EL0057425	502/2	EL0077250
b) 2 Position	502/5	EL0282734	502/6	EL0282735
c) 2 Pole	502/3	EL0077251	502/4	EL0077252
d) Rail-Connecting	502/7	EL0282806	502/8	EL0282807

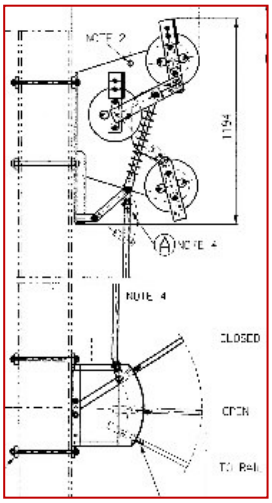
Table 38 - Drawings of various types of ART (Multi-Contact) Switches

The following is a summary of the different variants, along with a diagram to the right of each to help show the physical differences between them (these diagrams show the standard Left-hand versions only).

a) ***Isolating & Rail-Connecting Switch***

This switch has 3 terminals and 3 handle positions (*Closed*, *Open* and *To Rail*):

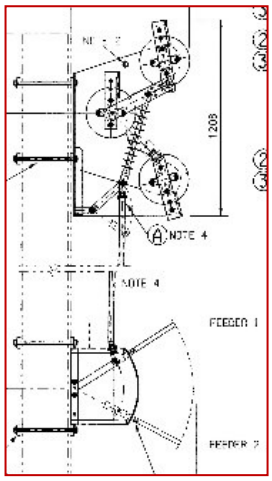
- The top terminal connects to the S/S or S/H feeder,
- The middle terminal connects to the OHW section (which can then be rail-connected), and
- The bottom terminal connects to rail.



b) ***2 Position Switch***

This switch also has 3 terminals, but is intended to feed power to either one section or another (Section 1 or Section 2), with no intermediate *Isolated* position:

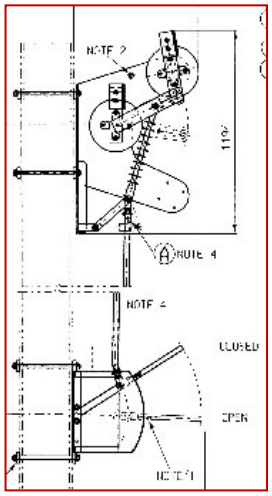
- The top terminal connects to OHW Section 1,
- The middle terminal (common) connects to the circuit that needs to select between Sections 1 and 2, and
- The bottom terminal connects to OHW Section 2.



c) ***2 Pole Switch***

This switch has only 2 terminals. It is intended to *Close* in the upper position and *Open* (isolate) in the lower position:

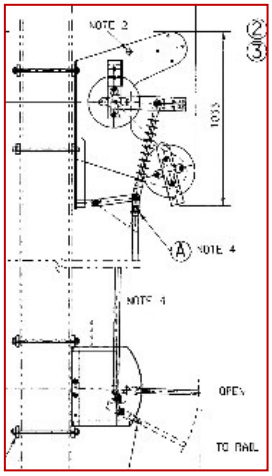
- The top terminal connects to one OHW section,
- The middle terminal connects to another OHW section.



d) ***Rail-Connecting Switch***

This switch also has only 2 terminals. It's intended to *Open* (isolate) in the midway position and close in the lower position (and this is normally *to Rail*):

- The middle terminal connects to one OHW section,
- The bottom terminal connects to rail.



3.7.4.5 Design Notes

AERIAL LOADING

The blade alignment of this switch can sometimes be affected by load movement of the aerial feeder wires connected to its terminals. So, it's important that these loads are minimised and/or the amount of regulated OHW movement (with temperature) is limited.

If the aerial feeder wire loads are not properly controlled, then the switch blade may not align properly with one or more switch terminals. This misalignment may make it difficult to physically close the switch in the required position from time to time, which can be somewhat unpredictable (depending on the aerial load position).

For long aerial feeds to the OHW of more than about 3m, this usually requires some form of additional conductor support along the way, and various "gallows" fittings have been designed and employed for this purpose – the twin suspension insulators at the end of the gallows support much of the feeder weight and reduce the amount of feeder wire movement, thus relieving the stress on the switch.

Refer to *Figure 422* further back for an example of a gallows fitting that supports the aerial feeder wires to the OHW.

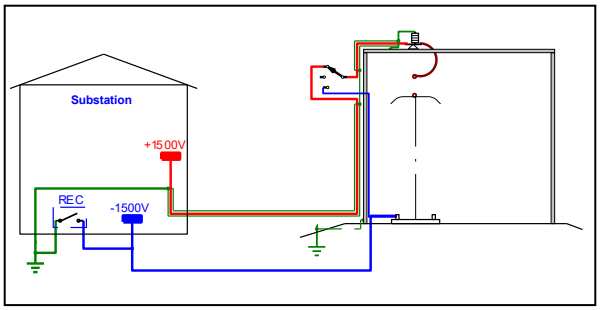
3.7.4.6 Status (c. 2014)

These switches are current.

3.7.4.7 Reference

See *Table 36* for drawing reference.

3.8 FEEDING



3.8.0 General

3.8.0.1 Description

Feeding arrangements occur at substations and sectioning huts, and at field switch locations.

They include runs of 1500V cable pairs and /or aerial feeder wires, which ultimately connect to the OHW conductors being fed.

3.8.0.2 Function

Feeding arrangements provide the means of reliably and safely transferring the +1500V current supply from *substations* and *sectioning huts* out to the OHW, which in turn feeds the electrical needs of nearby trains. (The negative return circuit through the tracks comes back to the substation via track-side negative impedance bonds.)

Feeding arrangements also occur at 1500V *switches* located adjacent to the track for the purpose of electrical sectioning.

Feeding arrangements can be classified as either:

- ***Cable Feeding***, or
- ***Aerial Feeding***.

Figure 441 shows very simple situations of *cable feed* (left diagram) and *aerial feed* (right diagram), connecting the substation to one OHW electrical section.

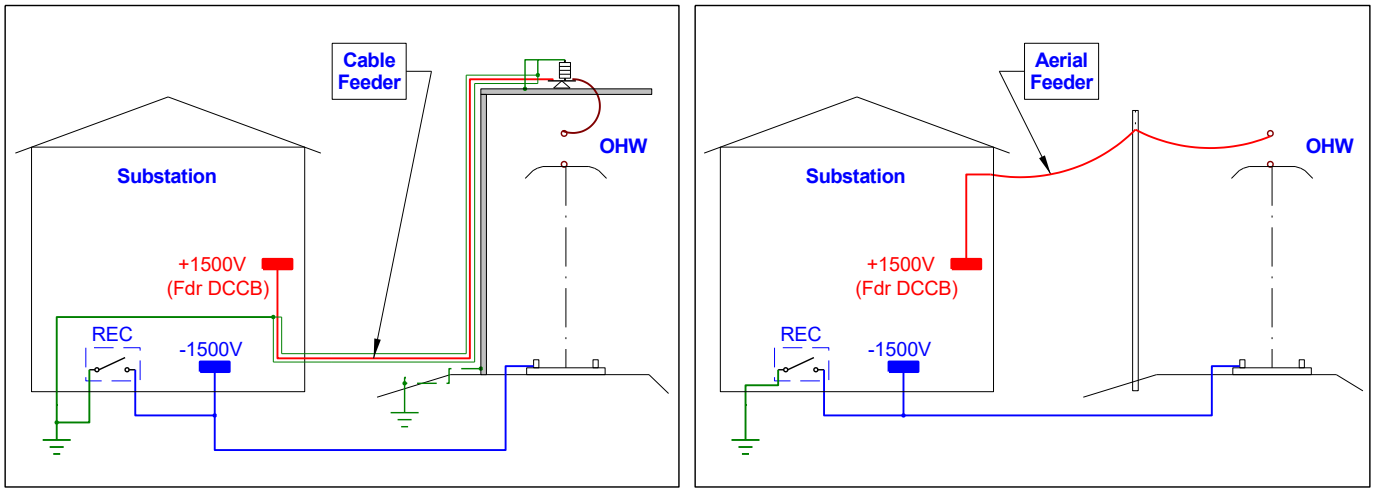


Figure 441 - Cable Feeding versus Aerial Feeding

There are many different scenarios, including those shown in *Appendix "B" – Switching & Feeding Situations* at the end of this document. (Note that these situations would typically also include a switch located on the S/S or S/H wall inside the yard, for more obvious electrical isolation of the OHW, rather than relying on an open DCCB located within a S/S or S/H that's hidden from view outside.)

3.8.0.3 Typical Components

The following main components are common to most feeding arrangements.

CABLE

1500V cable is most often used to transfer the electrical current from a substation or sectioning hut out to the OHW being fed. This cable is normally screened with a single layer of copper strands (typically totalling about 90mm²), which is intended to help with the electrical protection of the cables, especially when they head away from the well-controlled environment of a substation or sectioning hut.

The standard feeding cable has a multi-stranded 400mm² copper core with XLPE (cross-linked polyethylene) insulation rated for 3.8/6.6kV. From one manufacturer, its weight was about 5.6kg/m and had a Basic Insulation Level of 75kV. It can be seen further on in *Figure 446*.

Great care needs to be exercised when installing a cable, to prevent its outer plastic layer from being damaged or worn through over time, which may expose any underlying metallic screen.

CABLE TERMINATION

The end of a 1500V cable must be properly terminated with an appropriate lug. This commercial lug is a tin-plated copper tube that's flattened at one end and with 2 holes spaced 50mm apart for set screw fastening to other equipment (namely the copper plate here – see below). The 1500V cable core terminates within this circular copper tube, and a substantial mechanical crimp connection is then made, resulting in a solid and reliable low resistance cable connection suitable for passing high level currents.

For 1500V cables, a special *cable termination kit* is needed to absolutely prevent moisture ingress into this vital connection – any moisture leaking into the cable permanently damages the extremely important insulation within the 1500V cable. This kit includes special circular sheds that are placed on the outside of the cable to help increase the current leakage path during heavy rain, etc.

CABLE-TO-AERIAL TERMINATION

These days, a "Cable-to-Aerial Termination" arrangement is installed to provide for the termination of the lugged 1500V cables onto a long 160mm wide × 10mm thick copper termination plate, which is supported by a post type insulator from the OHW support structure. See *Figure 442*. It's installed at a position that's usually:

Figure 442 - Two Cable-to-Aerial Terminations being prepared

- Just above the OHW being fed, when mounted on a portal bridge, or
- Laterally adjacent to the OHW being fed, when installed on a mast.

The other end of the copper plate is designed for connecting the 2 bare (typically 270mm²) aerial feeders using a pair of U-bolted parallel feeder clamps per wire. The pair of U-bolts are required to provide an extremely robust mechanical connection, since the aerial feeder wires can move about under windy conditions, as well as move longitudinally with temperature changes in a regulated OHW system. But primarily it can achieve a reliable, very low resistance joint from plate to wire.

This arrangement would normally include a surge arrester for protecting the vital 1500V cable insulation.

Figure 443 is a photo of such an arrangement on a mast (the chain in the background is part of the adjacent cantilever). See also *Figure 449* for a current typical standard arrangement.

AERIAL FEEDER

These are short lengths – typically about 2m to 3m – of twin bare aerial wires that connect the OHW conductors to the copper termination plate, or to an adjacent switch. The aerial wire is usually 270mm² HDBC (catenary wire).

Sometimes much longer aerial feeder lengths have been run from an adjacent substation or sectioning hut out to the OHW, supported at a few locations along the way. See *Figure 445* (further on). This approach is no longer acceptable.

Also further on, *Figure 446* compares the 270mm² wire with the 400mm² cable.

CABLE SUPPORT

Regularly spaced cable clamps installed on steel brackets (with associated fasteners) ensure any exposed cable is well supported and restrained along its route.

The cable clamps are typically "Cabus" brand, with provision for a single bolt to clamp the cable and fasten it in place.

Sometimes the cable support arrangement may involve protecting the cable by some means or other.

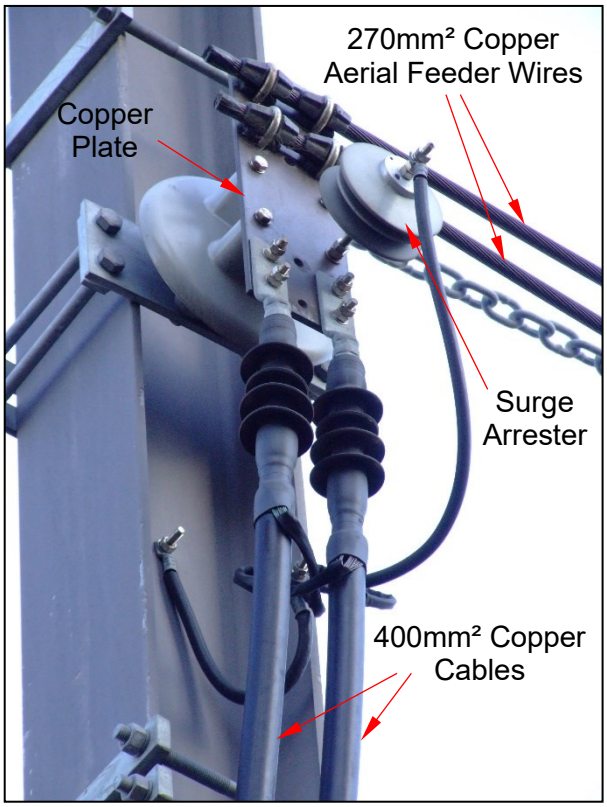


Figure 443 - Cable-to-Aerial Termination arrangement on a Mast

SURGE PROTECTION

Surge arresters help to protect the all-important insulation on 1500V cables from damaging lightning voltage surges travelling along the OHW conductors.

A surge arrester connects directly across from cable core (+1500V) to cable screen (- 1500V) and to earth, with leads as short as practical, so as to protect the cable insulation from over-voltages, and also to direct the surge away preferably to ground as soon as possible. Refer to *Section 3.9* for more details.

EARTHING

Special earthing considerations are applied to feeding arrangements, in an attempt to make the whole arrangement safe whilst also trying to prevent or limit any dc electrolysis leakage currents into the ground.

Earthing is a specialist area in Sydney's OHW system, so consult such people when encountering unusual earthing situations where this expert advice is required (especially during design work). Refer also to *Section 3.12*.

3.8.0.4 Configuration

TYPES OF FEED

There are two basic configurations:
Cable feed and ***Aerial feed***. (Some situations require a mix of both of these.)

In all cases, the final connection to the catenary wire is made with bare copper wire, typically employing at least 2 parallel U-bolt clamps onto each catenary.

Cable Feed

1500V cables are run from the *substation* or *sectioning hut* to a feeder mast or portal bridge, before being launched out to the OHW by local aerial feeders. Refer to left side of *Figure 441*. Also see *Figure 444* and *Figure 448*.

These 1500V cables can also run from local *switches* (installed on or near masts) to the aerial connection plate that then connects to the OHW.

For many decades now, the cable has been terminated on a *cable-to-aerial termination arrangement*. This incorporates a thick copper plate installed on a post type insulator that's mounted on a mast at about catenary height, or on a portal bridge located above the catenary.

The final feed to OHW is by a 1m or so length of twin aerial feeder wires, from the copper plate to catenary feeding point.

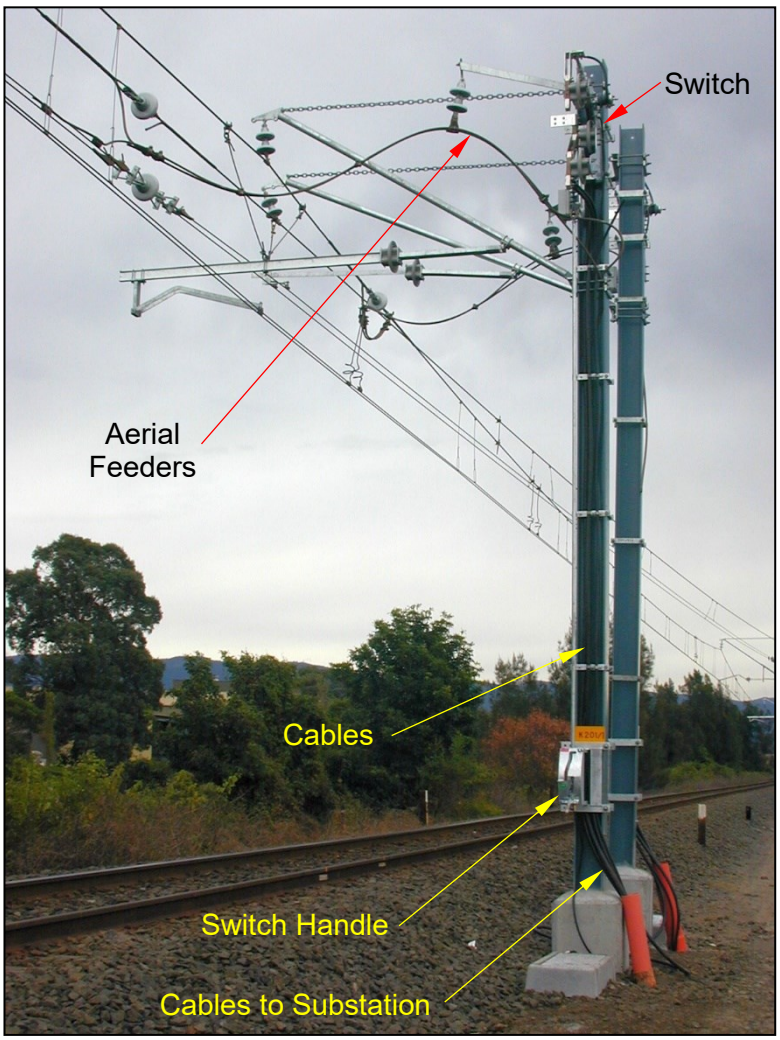


Figure 444 - Cable Feed from Substation (with Switch)

A surge arrester is installed at the cable termination to protect the cable against insulation puncture damage from lightning surges.

If the cable terminates onto to a switch, as in the case of *Figure 444*, the switch terminals themselves can take the place of the cable-to-aerial termination arrangement. In this case, the aerial feeders to the OHW connect to the switch terminals also.

Aerial Feed

Bare aerial wires are strung from the substation or sectioning hut to a track-side feeder structure, then out to the OHW conductors. See right side of *Figure 441* and to *Figure 445*.

This approach relies on attaining suitably high vertical clearances to surrounding infrastructure, to vehicles passing underneath and to people (for safety), but is far cheaper than the cable feed alternative. There are many examples of this configuration scattered throughout the electrified network.

However, one of the greatest challenges with this approach is to control the risk (over time) of people or mobile equipment getting too close to the live bare wires above. I understand there have been a number of instances where people had built up the ground level under aerial feeders (with soil or some other structure such as a shed?), and unwittingly reduced the safety clearances to the bare live wires above. (Unlike the track itself, the area to the side of the rail corridor is much less well controlled in terms of the ability for people to radically alter its ground levels!) Statutory clearances must be maintained, and measuring/checking this would be an ongoing maintenance task. Appropriate signage may help in this regard.

Another risk is that the aerial feeder wire snaps near the OHW structure (for whatever reason) and falls to ground. In this case, there's hopefully good a chance that the broken wire touches ground, trips the substation's rail-earth contactor (shorting rail to earth) so as to develop enough dc fault current to trip the associated dc circuit breaker, to isolate supply and render the situation safer. But there may also be a chance that it doesn't, that there simply isn't enough current to trip the DCCB, and the wire on the ground instead remains alive! This is much the same as the risks of using dc auxiliary feeders at locations well away from the track (see *Section 3.1.1.5, Location of Auxiliary Feeders*).

Overhead lineworkers in particular need to be more aware of the exposed aerial feeders and the potential hazards they pose. This is particularly true if *live* feeders pass over a track with its own OHW isolated & rail-connected for maintenance work. It is absolutely essential that statutory clearances be maintained from workers to live conductors. An example could be if the left track in *Figure 445* is isolated and rail-connected for maintenance, but the right track remains alive, so some of the aerial feeders directly over the left track would be alive! (*Figure 510* further on shows a cross-track view of the aerial feeders to the OHW here.)

Figure 445 - Aerial Feeders at Blaxland Substation

Also, aerial feeds are more exposed and vulnerable to the outside elements (e.g. lightning, falling trees, earth moving equipment, etc.).

In order to mitigate the obvious additional risks of using this approach, aerial feeds from substations or sectioning huts are no longer deemed suitable for future works (that is, unless some risk study is conducted, and with acceptable outcomes).

Cable feed, whilst initially more expensive, is the superior choice in both short and long term.

FEEDER CABLE

These days, feeder cables consist of 2 × 400mm² XLPE cables (although a load flow study may determine that more copper is needed, so we are sometimes seeing 3 or 4 cables run in parallel now). Refer to *Figure 444* and *Figure 448*.

These 46mm diameter cables are typically supported and restrained by special "Cabus" single-bolt aluminium cable clamps, spaced up to 1,000mm apart. The huge fault levels of the dc system (up to about 50kA in certain areas I believe), necessitates that the cables be rigidly restrained to prevent the large dynamic forces, under fault conditions, causing the cables to whip about and damage themselves and other nearby equipment.

The cables may need to be derated if they're located close to each other, if they're located underground, and/or if they're in a position that exposes them to additional heat (such as solar radiation with limited cooling cross winds), etc. In other words, any situation that may cause the copper core temperature and surrounding insulation to rise to unacceptable levels as determined by the cable manufacturer. Derating calculations can determine the outcome.

AERIAL FEEDER WIRE

The standard aerial feeder comprises 2 × 270mm² hard drawn bare copper wires, with parallel U-bolt clamps keeping them together every 1,000mm or so along their route.

In the past, various projects used aerial feeder wires that matched the catenary wire (e.g. Gosford to Newcastle used 327mm² to catenary & 165mm² to the large 193mm² contact wire). However, 270mm² wire is the most sensible size to use as a standard.

TMP Code	Equipment Name	Made By	Drawing No.
EP-08-41-00-00	**Feeding Arrangements**		
EP-08-41-01-00	*Cable Feeding Arrangement (General)*	*RailCorp*	*B/83384 Sh. 2*
EP-08-41-21-00	*Aerial Feeding Arrangement (General)*	*RailCorp*	*K/83740*

Table 39 - Typical Feeding arrangement drawings

A sample Feeding Arrangement drawing is included in *Figure 728* in *Section 10.1*. This has two Detail views that show how the cable-to-aerial termination arrangement is configured.

3.8.0.5 Design Notes

DESIGN OF FEEDING ARRANGEMENTS

If a mast or portal leg is installed next to the track being fed, this can result in a fairly simple and straightforward feeding arrangement from that structure. There are usually standard arrangements that can be used (referenced in the design) to describe the mechanical details needed for accurately constructing the feeding arrangement.

However, where the OHW is fed from the bridge of a portal structure (usually needed where the feeds are run over to remote tracks), the design details needed for constructing the feeding arrangement usually aren't that straightforward. And there's normally no standard arrangement that can be readily referenced to describe the exact situation to build here. This is because there are so many variables and possibilities.

In this case, it needs a sizeable effort in the design process to design each arrangement almost from scratch, while adhering to the standards and project specifics (especially electrical sectioning requirements).

All details, down to the nuts & bolts, need to be described in the design drawing, for it to have any chance of being built to the designer's satisfaction whilst embracing the various standards (which can also change over time).

Adding local switches onto the OHW structure usually complicates the feeding arrangement, and the mechanical details of the feeding need to be worked through.

Of particular value on the feeding arrangement drawing is the generated "*Bill of Materials*", which the constructor needs to reference when purchasing items.

The feeding arrangement drawing also includes "*Notes*" that need to be referred to by the constructor when building the arrangement. Some of the notes can have significant importance, so in case of any doubts, the designer should be consulted.

Earthing and bonding can add another level of complexity, which the designer needs to work through and document on the design drawings for the feeding arrangement. The design should also consider any surge protection of cables. So, these aspects can require talking to the experts in *earthing and bonding* due to the subtleties of a dc traction system, and it should then require their endorsement signature on the design drawing/s.

Having designed many switching and feeding arrangements throughout my career, I can attest to the difficulty and time-consuming nature of designing the more complicated feeding arrangement drawings. Examples include North Sydney 7-Switch Bank shown in *Figure 418* (requiring 6 × A1-size design drawings), and Chatswood 8-Switch Bank in *Figure 419* (requiring 4 × A1-size design drawings).

I have put together some of the more straightforward scenarios for switching and feeding in *Appendix "B" – Switching & Feeding Situations*. Note however that it's important that the specifics of each case be checked against current standards (which can also change in time), to confirm their relevancy before designing each situation.

Lastly, there are risks like *access prevention* to consider in some situations (to help protect people from doing dumb things). If a situation is considered too risky, the solution will likely involve Civil Design to document a suitable barrier arrangement on their OHW structure design drawing (e.g., location and design details of access prevention grills on each portal leg or on the portal bridge itself). See the heading *Anti-Climbing Mechanisms* below, and *Figure 451* for instance.

CABLE SIZE VERSUS AERIAL FEEDER SIZE

The usual 1500V cable has 400mm² of copper as the core of the cable. This is surrounded by XLPE insulation (with semi-conductive screens each side) rated at 3.8/6.6kV, and then a 90mm² copper screen layer (for an electrical protection barrier) and finally more plastic insulation to the cable's robust surface.

Refer to *Figure 446* for the typical composition of XLPE cable. There's usually 2 of these cables installed in parallel to get the required current rating without overheating (i.e. keeping the core temperature down to a certain temperature). In some special circumstances the design my require 3 or even 4 cables in parallel.

Figure 446 also contrasts this feeder cable to the aerial feeder wire size of 270mm² at the other end of the copper plate (the same scale was used). Two of these bare wires (no insulation) are run in parallel to connect to the OHW.

I'm only guessing here (?), bit it's likely that both the 400mm² cable and 270mm² HDBC wire have similar continuous current ratings, even though the cable is more than twice the external diameter of the wire (46.5mm versus 21.3mm). It is also more than twice as heavy (55N/m versus 24N/m). The copper core of the cable is 23.6mm diameter versus 21.3mm diameter for the bare feeder wire.

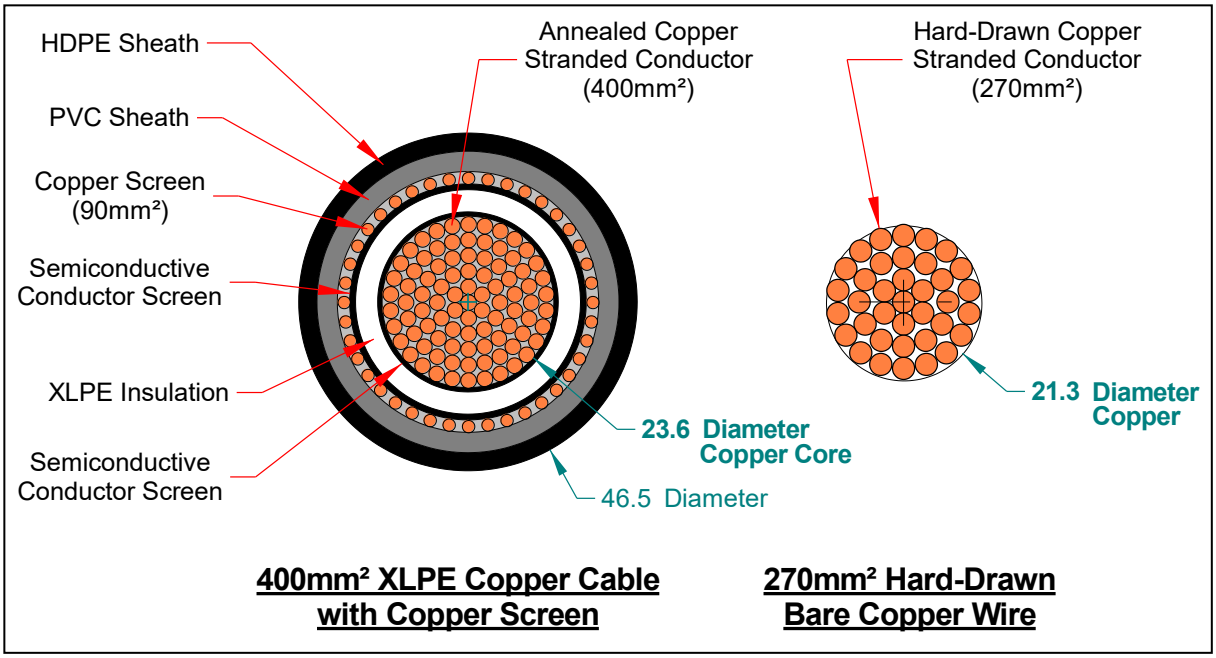


Figure 446 - Size comparison between 400mm² Cable & 270mm² HDBC Wire

The apparent mismatch in copper sizes for similar current ratings – 400mm² versus 270mm² – is explained below.

Heat is generated due to the power loss when a conductor passes heavy current in a copper wire with resistance "R", viz. $P_{loss} = I^2.R$

Any heat energy generated over time by the $I^2.R$ losses in the 270mm² bare aerial feeder wire can readily be transferred to the surrounding environment, either by radiation, convection, or even conduction (if there's a nearby clamp or other significant mass that can transfer the heat away). A greater wire temperature rise drives a greater heat transfer rate back to ambient temperature, which helps to keep the wire cooler than it would otherwise be. So, this bare 270mm² wire has good *thermal efficiency*.

On the other hand, if the insulated cable had a copper size of the same 270mm², it would need to be derated (pass less current) to cope with the heat generated by $I^2.R$ losses, because of its reduced ability to expel this heat due to the thick XLPE insulation and other layers within the cable. The extra insulation layers in cables tend to trap or store the heat, so the temperature at the copper core stays at a higher level than that for bare copper wire equivalent. In order to make up for this adverse outcome, more copper cross-sectional area is needed so as to reduce the resistance (R) and thus reduce the amount of heat generated in the first place ($I^2.R$). This is needed in order to keep the copper from exceeding its maximum temperature of somewhere around 90°C I think (although in this case, the conductor is not under mechanical tension). In any case, the XLPE insulation is also critically limited to about 120°C for continuous use.

It is fortunate that both these conductors – the bare aerial wire and the insulated cable – normally experience varying loads over relatively short periods of time, i.e. as trains accelerate (drawing heavy current) and then coast (drawing small current). It would be far worse if the heavy current loads remained constant for 10s of minutes or more, because that would require much larger conductors or additional conductors in parallel (which is preferred because of the above reasoning).

Note that the reduced resistance from a larger copper size of 400mm² is also good for the DCCB settings in the electrical protection system.

CATENARY FEEDING LOOP

A feeding connection to the OHW involves installing a relatively short aerial feeder (twin 270mm² wires), which needs to be electrically connected, via multiple U-bolt clamps, to the catenary wire/s (and with in-span feeders then connected down to the contact wire/s). This large amount of copper connecting to catenary reduces the likelihood of OHW conductors breaking due to overheating, then annealing and stretching at the electrical connections. (This is mostly due to the exceptionally high traction load currents placed on much of the electrical network these days.)

Although there are some old examples in the field, direct feeding to the catenary wire in tension is *not* normally permitted these days.

So, ***a feeder loop should be established in the catenary, then the aerial feeder is connected to this untensioned loop*** – see *Figure 450* for an example of feeder loop makeup. (Alternatively, the connection can be to a catenary feeding tail – see next subsection.)

The reason is that any loose connection to a highly-tensioned catenary can cause localised overheating of the connection, which can result in annealing of the catenary. Once the catenary is annealed, it loses its strength, causing it to stretch and weaken and eventual snap. OHW falls down. However, if the connection of the feeder wire is to an untensioned catenary, this can overheat to a much greater extent without causing the same problem.

This feeder loop arrangement typically has an insulator taking the full mechanical tension. I understand the insulator is there to ensure no dc current passes through any 19mm diameter stainless steel pins used in the arrangement.

CATENARY FEEDING TAIL

The alternative to the catenary feeding loop is simply feeding to the catenary "*tail*" which comes out from a catenary terminating clamp.

In this situation, the tail is under no mechanical tension, so a heavy current connection can be readily made to the feeder wire (provided the tail is long enough for the necessary number of parallel clamp U-bolt attachments).

CLEARANCES

It's obvious that the full electrical clearance is required between feeder wires of different electrical sections (i.e. 150mm absolute minimum in their closest worst-case position).

But a second concern is that great care must be taken to ensure that any bare feeder wires do not rest or intermittently touch other bare wires or equipment *of the same electrical section*.

Even though they will always be at the same potential, if wires are allowed to touch other wires or equipment, then it's possible for intermittent low-level arcing to take place on the outer strands that actually touch, particularly if there's some movement between the 2 items. Any such arcing is more likely during times when heavy feeding current is being drawn through these wires (the current will find any path it can take). Over time, the affected

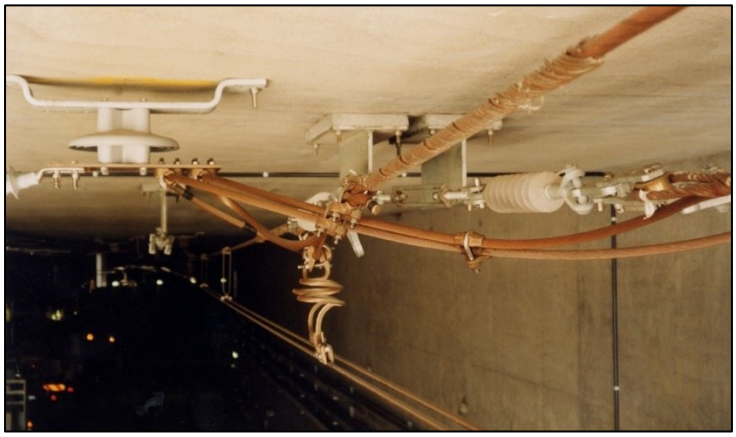


Figure 447 - Aerial Feeders in a tight tunnel (Airport Line)

strands can erode and break, jeopardising the reliability of the OHW.

Although this situation could occur anywhere, it is more likely to happen in the tight confines of a tunnel situation (see *Figure 447*), where it is sometimes difficult to adjust to get the required clearances.

Having said that, long lengths of unrestrained bare feeder wires can also touch other parts of the same section – even if reasonable clearances are in place – due to strong or gusty winds in the outside environment.

An intermediate support (such as a "gallows" fitting) can help in this regard, by reducing the length of unrestrained conductor for better physical control of the wire, especially during times of gusty winds or other causes of wire movement.

Figure 448 shows a *gallows fitting* near the top of each mast. They act to reduce the length of unrestrained aerial feeder wire.

These wires connect from the cable termination on each mast, and span out to attach to the appropriate catenary & contact wires. This distance can be a very long 3.5m or so.

The gallows fitting supports the feeder wires about midway, and so reduces the resulting 2 spans to about half that value.

Figure 448 - Standard Cable-to-Aerial Feeding from Masts

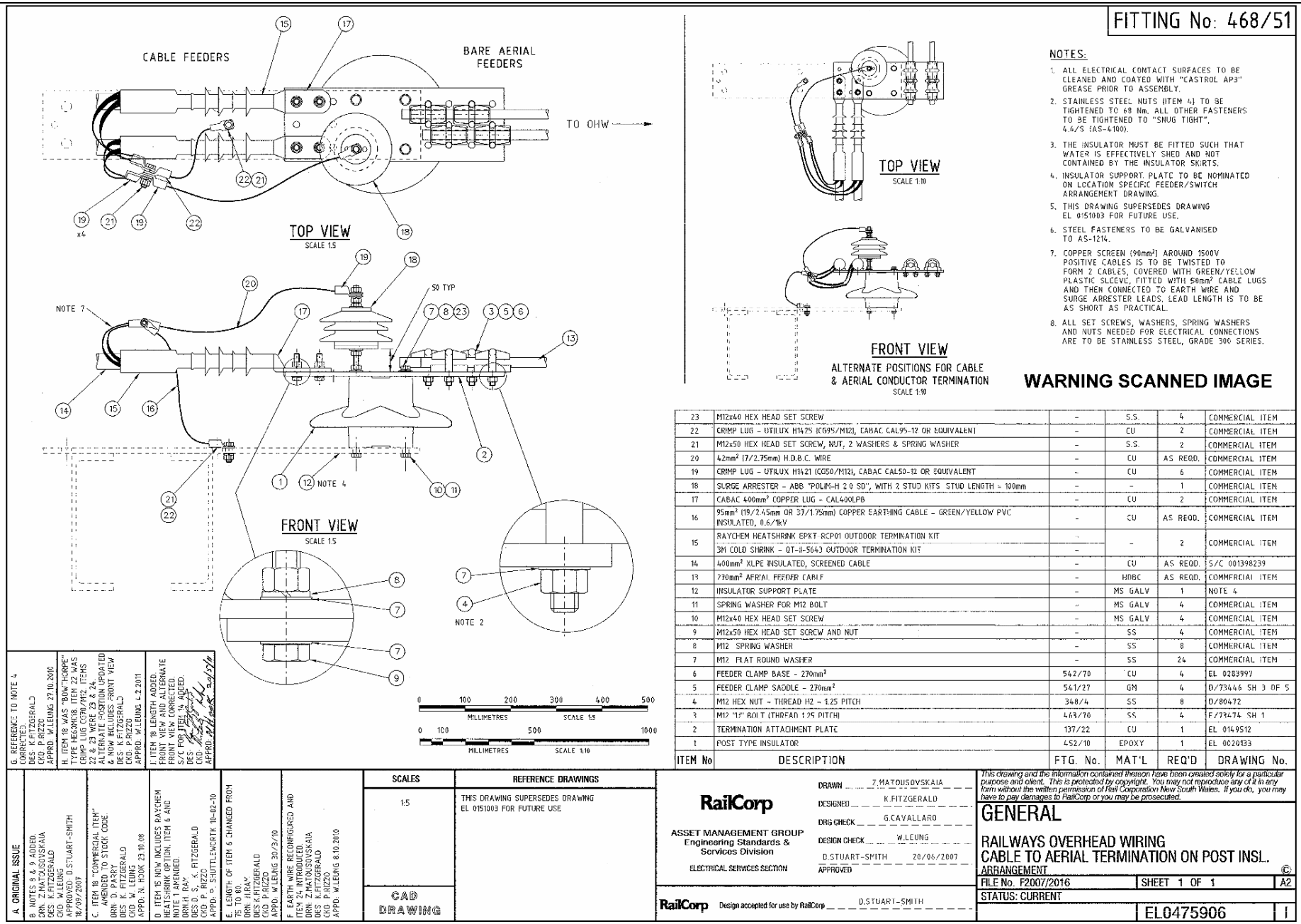
So, the gallows fittings help control the wire's position so that it never comes near equipment it's not meant to be near (including the mast). This is even with extreme wind gusts, and with the wires, and their supporting cantilevers, moving longitudinally under extreme temperature limits (hot and cold).

CABLE DERATING

The heat generated inside cables when passing heavy current, needs to be effectively transferred radially out to the cable surface and dissipated to the cooler surroundings.

However, if the surroundings don't allow this, e.g. due to other hot cables nearby, and this heat is allowed to build up, then the copper core temperature, and (more importantly) the surrounding insulation, may reach unacceptable levels and cause damage to the cable.

If this is likely to happen, then the cable rating should be lowered, i.e. passing less current and/or for shorter periods of time, in order to not let it overheat. Calculations are needed.


FITTING No: 468/51
CABLE FEEDERS
BARE AERIAL FEEDERS
TO OHW
TOP VIEW
SCALE 1:5
FRONT VIEW
SCALE 1:5
NOTE 2
NOTE 4
NOTE 7
S0 TYP
TOP VIEW
SCALE 1:10
FRONT VIEW
ALTERNATE POSITIONS FOR CABLE & AERIAL CONDUCTOR TERMINATION
SCALE 1:10
NOTES:
1. ALL ELECTRICAL CONTACT SURFACES TO BE CLEANED AND COATED WITH "CASTROL AP3" GREASE PRIOR TO ASSEMBLY.
2. STAINLESS STEEL NUTS (ITEM 4) TO BE TIGHTENED TO 68 Nm. ALL OTHER FASTENERS TO BE TIGHTENED TO "SNUG TIGHT", 4.6/S (AS-4100).
3. THE INSULATOR MUST BE FITTED SUCH THAT WATER IS EFFECTIVELY SHED AND NOT CONTAINED BY THE INSULATOR SKIRTS.
4. INSULATOR SUPPORT PLATE TO BE NOMINATED ON LOCATION SPECIFIC FEEDER/SWITCH ARRANGEMENT DRAWING.
5. THIS DRAWING SUPERSEDES DRAWING EL 0151003 FOR FUTURE USE.
6. STEEL FASTENERS TO BE GALVANISED TO AS-1214.
7. COPPER SCREEN (90mm²) AROUND 1500V POSITIVE CABLES IS TO BE TWISTED TO FORM 2 CABLES, COVERED WITH GREEN/YELLOW PLASTIC SLEEVE, FITTED WITH 50mm² CABLE LUGS AND THEN CONNECTED TO EARTH WIRE AND SURGE ARRESTER LEADS. LEAD LENGTH IS TO BE AS SHORT AS PRACTICAL.
8. ALL SET SCREWS, WASHERS, SPRING WASHERS AND NUTS NEEDED FOR ELECTRICAL CONNECTIONS ARE TO BE STAINLESS STEEL, GRADE 300 SERIES.
WARNING SCANNED IMAGE
0 100 200 300 400 500
MILLIMETRES SCALE 1:5
0 100 500 1000
MILLIMETRES SCALE 1:10
G. REFERENCE TO NOTE 4 CORRECTED. DES: K.FITZGERALD CKD: P.RIZZO APPRD: W.LEUNG 27.10.2010
H. ITEM 18 WAS "BOW THORPE" TYPE HEADWORK ITEM 22 WAS CRIMP LUG ITEMS 23 & 24 WERE 23 & 24 ALTERNATE POSITION UPDATED & NOW INCLUDES FRONT VIEW DES: K.FITZGERALD CKD: P.RIZZO APPRD: W.LEUNG 6.2.2011
I. ITEM 18 LENGTH ADDED. FRONT VIEW AND ALTERNATE FRONT VIEW CORRECTED. S/C FOR ITEM 14 ADDED. DES: CKD: APPRD:
A ORIGINAL ISSUE
B. NOTES 3 & 9 ADDED. DRN: Z.MATOUSOVSKAIA DES: K.FITZGERALD CKD: W.LEUNG APPROVED: D.STUART-SMITH 18/09/2007
C. ITEM 18 "COMMERCIAL ITEM" AMENDED TO STOCK CODE. DRN: D. RAY DES: K. FITZGERALD CKD: W. LEUNG APPD: N. HOOK 23.10.08
D. ITEM 15 NOW INCLUDES RAYCHEM HEATSHRINK OPTION. ITEM 6 AND NOTE 1 AMENDED. DRN: D. RAY DES: K. FITZGERALD CKD: P. RIZZO APPD: D. STUTTLE/CORTN 10-02-10
E. LENGTH OF ITEM 6 CHANGED FROM 75 TO 80. DRN: J.RAY DES: K.FITZGERALD CKD: P.RIZZO APPD: W.LEUNG 30/3/10
F. EARTH WIRE RECONFIGURED AND ITEM 24 INTRODUCED. DRN: Z.MATOUSOVSKAIA DES: K.FITZGERALD CKD: P.RIZZO APPD: W.LEUNG 8.10.2010

ITEM No	DESCRIPTION	FTG. No.	MAT'L	REQ'D	DRAWING No.
23	M12x40 HEX HEAD SET SCREW	-	S.S.	4	COMMERCIAL ITEM
22	CRIMP LUG - UTILUX H1475 (CG95/M12), CABAC CAL95-12 OR EQUIVALENT	-	CU	2	COMMERCIAL ITEM
21	M12x50 HEX HEAD SET SCREW, NUT, 2 WASHERS & SPRING WASHER	-	S.S.	2	COMMERCIAL ITEM
20	42mm² (7/2.75mm) H.D.B.C. WIRE	-	CU	AS REQD.	COMMERCIAL ITEM
19	CRIMP LUG - UTILUX H1421 (CG50/M12), CABAC CAL50-12 OR EQUIVALENT	-	CU	6	COMMERCIAL ITEM
18	SURGE ARRESTER - ABB "POLIM-H 2.0 SD", WITH 2 STUD KITS STUD LENGTH = 100mm	-	-	1	COMMERCIAL ITEM
17	CABAC 400mm² COPPER LUG - CAL400LPB	-	CU	2	COMMERCIAL ITEM
16	95mm² (19/2.45mm OR 37/1.75mm) COPPER EARTHING CABLE - GREEN/YELLOW PVC INSULATED, 0.6/1kV	-	CU	AS REQD.	COMMERCIAL ITEM
15	RAYCHEM HEATSHRINK EPKT RCP01 OUTDOOR TERMINATION KIT 3M COLD SHRINK - QT-II-5643 OUTDOOR TERMINATION KIT	- -	-	2	COMMERCIAL ITEM
14	400mm² XLPE INSULATED, SCREENED CABLE	-	CU	AS REQD.	S/C 001398239
13	270mm² AERIAL FEEDER CABLE	-	HDBC	AS REQD.	COMMERCIAL ITEM
12	INSULATOR SUPPORT PLATE	-	MS GALV	1	NOTE 4
11	SPRING WASHER FOR M12 BOLT	-	MS GALV	4	COMMERCIAL ITEM
10	M12x40 HEX HEAD SET SCREW	-	MS GALV	4	COMMERCIAL ITEM
9	M12x50 HEX HEAD SET SCREW AND NUT	-	SS	4	COMMERCIAL ITEM
8	M12 SPRING WASHER	-	SS	8	COMMERCIAL ITEM
7	M12 FLAT ROUND WASHER	-	SS	24	COMMERCIAL ITEM
6	FEEDER CLAMP BASE - 270mm²	542/70	CU	4	EL 0283997
5	FEEDER CLAMP SADDLE - 270mm²	541/27	GM	4	D/73446 SH 3 OF 5
4	M12 HEX NUT - THREAD M2 - 1.25 PITCH	348/4	SS	8	D/80472
3	M12 "U" BOLT (THREAD 1.25 PITCH)	463/76	SS	4	F/73474 SH 1
2	TERMINATION ATTACHMENT PLATE	137/22	CU	1	EL 0149512
1	POST TYPE INSULATOR	452/10	EPOXY	1	EL 0020133

SCALES: 1:5
CAD DRAWING

REFERENCE DRAWINGS: THIS DRAWING SUPERSEDES DRAWING EL 0151003 FOR FUTURE USE

RailCorp
ASSET MANAGEMENT GROUP
Engineering Standards & Services Division
ELECTRICAL SERVICES SECTION

DRAWN Z.MATOUSOVSKAIA
DESIGNED K.FITZGERALD
DRG CHECK G.CAVALLARO
DESIGN CHECK W.LEUNG
APPROVED D.STUART-SMITH 20/06/2007

RailCorp Design accepted for use by RailCorp D.STUART-SMITH

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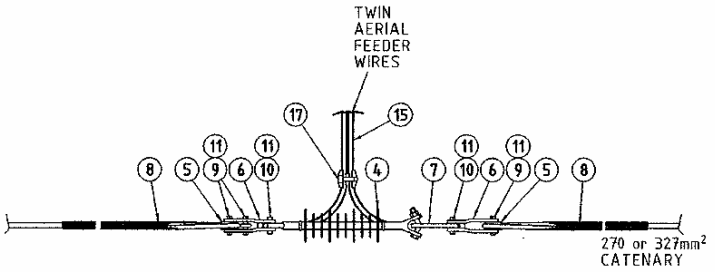
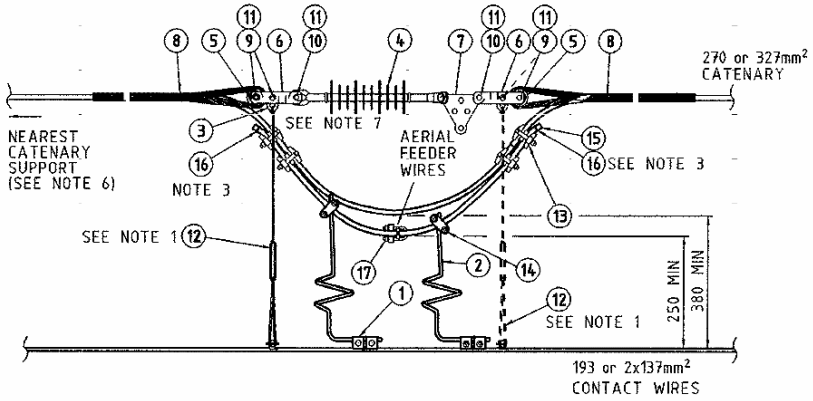
GENERAL
RAILWAYS OVERHEAD WIRING
CABLE TO AERIAL TERMINATION ON POST INSL.
ARRANGEMENT ©
FILE No. F2007/2016 SHEET 1 OF 1 A2
STATUS: CURRENT
EL0475906 1

Figure 449 - Typical Cable-to-Aerial Feeder Termination arrangement on Mast or Portal

FITTING 58/10



PLAN VIEW
1 : 20
(CONTACT OMITTED FOR CLARITY)



ELEVATION
1 : 20

0 0.5 1 2 SCALE 1:20

APPLICABLE OHW SYSTEMS

CATENARY	CONTACT
270mm²	193mm²
327mm²	193mm²
270mm²	2x137mm²

NOTES:

1. ARRANGEMENT SUITABLE FOR SINGLE CATENARY WITH SINGLE OR TWIN CONTACT WIRES. TWIN CONTACT WIRES AS SHOWN, ARE SEPARATED BY 50mm WITHIN THIS BAY. FOR 150mm CONTACT SPACING INSTALL SECOND DROPPER AS SHOWN DOTTED. REFER ITEM 12.
2. CATENARY TO CONTACT FEEDER WIRE (ITEM 2) TO HAVE ITS CUT ENDS PROJECTING 10mm THROUGH CONTACT FEEDER CLAMP (ITEM 1).
3. S.S. HOSE CLIP (ITEM 16) TO BE INSTALLED AT END OF CATENARY FEEDER WIRE TO PREVENT STRANDING.
4. ALL CONNECTION SURFACES OF CLAMPS, FEEDERS, JUMPERS, CATENARY AND CONTACT WIRES TO BE CLEANED AND COATED WITH CASTROL "EPL3" GREASE PRIOR TO ASSEMBLY.
5. ALL FEEDER CLAMP NUTS TO BE TIGHTENED TO "SNUG TIGHT", 4.6/S (AS 4100).
6. DROPPER (ITEM 12) TO BE MADE OFF ON SITE AND SECURED TO CATENARY USING A CHAIN LINK (ITEM 3) AND PIN (ITEM 9) INTO THE CLEVIS LINK (ITEM 6) CLOSEST TO CATENARY SUPPORT.
7. FEEDER LOOP AND CLAMPS MUST REMAIN CLEAR OF DROPPER (ITEM 12).
8. ALL DIMENSIONS IN MILLIMETRES.

WARNING SCANNED IMAGE

ITEM	DESCRIPTION	FITTING No.	DRAWING No.	SINGLE CONTACT REQUIRED	TWIN CONTACT REQUIRED
17	CATENARY FEEDER CLAMP (270/270mm²)	54/24	D/73446 Sh.1	1	1
16	25mm DIAMETER S.S. HOSE CLIP	–	COMMERCIAL ITEM	2	2
15	270mm² H.D.B.C. (37/3.05mm)	–	–	2	2
14	CATENARY CLAMP	54/34	E/75526	2	2
13	CATENARY FEEDER CLAMP (270/270mm²)	54/24	D/73446 Sh.1	4	4
	CATENARY FEEDER CLAMP (327/270mm²)	54/27	D/73446 Sh.1		
12	DROPPER ARRANG'T – 50mm SPACING	474/–	D/80589 Sh.2	–	1
	DROPPER ARRANG'T – 150mm SPACING	474/–	D/80649 Sh.2	–	2
	DROPPER ARRANG'T – SINGLE CONTACT	474/–	D/80649 Sh.2	1	–
11	SPLIT PIN HP/A (NOTE 1)	710/2	COMMERCIAL ITEM	10	10 or 12
10	STAINLESS STEEL PIN	120/5	E/73596	2	2
9	STAINLESS STEEL PIN (NOTE 1)	120/14	E/73596	3	3 or 4
8	HELICAL ANCHOR (270mm²)	282/2	A3/89294	2	2
	HELICAL ANCHOR (327mm²)	282/3	A3/89372		–
7	TRIANGLE LINK PLATE	601/63	A4/89278	1	1
6	CLEVIS LINK	312/30	A3/89215	2	2
5	THIMBLE	105/45	A3/89214	2	2
4	120kN COMPOSITE INSULATOR	453/16	EL 0216729	1	1
3	CHAIN LINK (NOTE 1)	144/4	E/83627	1	1 or 2
2	IN-SPAN FEEDER	475/–	C/75333 Sh.2	2	2
1	FEEDER CLAMP	56/14	D/83169	2	2

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A ORIGINAL ISSUE
B. ORIGINAL FITTING No. 58/8 WAS DUPLICATED. NOW CHANGED TO 58/10. DRN: K.F. CKD: T.C.B. 6.7.01
C. ITEM 8 WAS SHOWN AS "252/3" DRN: Z.M. K..F. 17/10/01 CKD: T.G.B. 17/10/01
D. ITEM 17 CORRECTED ON PLAN VIEW, ELEVATION & PLAN VIEW SWAPPED. DES: K.F. CKD: W.L. APP: N.HOOK 8/11/09
E. OHW SYSTEMS TABLE ENTRY CORRECTED. ORIGINAL ENTRY OF 2x270mm² CHANGED TO 2x137mm² DRN: DES: CKD: APP: 19/12/09

SCALES
1:20

CAD DRAWING

owner and maintainer of the new rail network
RAILINFRASTRUCTURE CORPORATION

RIC CONSULTING ELECTRICAL DESIGN

DRAWN Z.MATOUSOVSKAIA
DESIGNED KEN FITZGERALD
DRG CHECK K.BIRMINGHAM
DESIGN CHECK S.NIDAGAL
PROJECT LEADER KEN FITZGERALD
J.PROCHAZKA 23/08/01
MANAGER, ELECTRICAL DESIGN DATE

GENERAL

RAILWAYS OVERHEAD WIRING
CATENARY FEEDING LOOP
ARRANGEMENT

PROJECT No. | SHEET 1 OF 1 | A3
T.M.C. ID. | EL 0027472 | E

Figure 450 - Typical OHW Feeding Loop connection (to Catenary & Contacts)

MINIMUM BENDING RADIUS OF CABLE

Cables are expensive to purchase (relative to bare aerial conductors), they are expensive to install, and they are relatively fragile, so they must be treated with a great deal of care.

Because of the added thickness of the various insulation layers surrounding the copper core in a cable, during installation the cable should not be bent any tighter than the specified "*minimum bending radius*" for that particular cable. (If you try to bend a short length of large diameter plastic tube it eventually buckles due to applied stresses, and this gives a bit of an idea of the nature of part of the problem with bending cables.)

Ideally, cables should be installed in a straight line, but in the real world cables need to bend in all sorts of directions along their route. Even a slight bend in the cable can cause added mechanical and electrical stresses within the cable, so there must be a practical limit – the minimum bending radius – so as to not overstress the cable and ensure a long life.

Failure to adhere to this bending requirement may lead to increased likelihood of cable failure, either immediately it's energized or at some time in the future, leading to a reduced life span. Unfortunately, this can be somewhat unpredictable if the installers do the wrong thing and no one notices. So, the installation procedure should include some control of bending radius in this regard, and controls should be put in place to ensure that it's actually carried out in a proper manner.

There are usually 2 bending radius figures provided by the manufacturer of the cable:

- ***Install*** – When the cable is initially installed. The bending radius is greater here (less tight) to help ensure the cable doesn't get overstressed during the general pulling and pushing when manipulating it to get to somewhere near its final position.
- ***Set*** – When the cable is finally set in position (where its position should not change). When all the above manipulating of the cable is done, it can then be put into a slightly tighter final position with a reduced bending radius, and left that way.

This approach of working to 2 different bending radii should allow better control, to help ensure the cable doesn't bend tighter than the manufacturer recommends, and thus prolong its life. The manufacturer's product warranty should then also be left intact.

We used to include the following standard note on new drawings of feeding or switching arrangements that called for the use of 1500V 400mm² screened XLPE cables:

> *"The minimum bending radius of XLPE cable is 25 times the cable diameter when installing, and 15 times when set (1,050mm and 630mm respectively for 400mm²)".*

Because the approach may change in time, refer to the current standards for the latest bending radii figures and approach. The manufacturer may also change details over time.

COPPER PLATE

In most cable feeding arrangements, the cable terminates at one end of a long 160mm wide × 10mm thick copper plate that is rigidly supported by a post type insulator installed onto the OHW structure. Aerial feeder wires are connected at the other end of the copper plate, that then connect to the OHW. Refer to *Figure 449* – Item 2 is the copper "termination attachment plate".

The copper plate adds convenience and practicality in a number of ways.

- The copper plate can be *installed* just about anywhere along the horizontal portal bridge or vertical mast. Its position is usually best suited to the aerial connection to the OHW,

which is typically about 1m vertically away (from portal bridge) to 3m horizontally away (from vertical mast).

- The pair of cables can be *terminated* with cable lugs (as part of the cable termination kit) which can then connect to the copper plate with 2 stainless steel set screws, providing a very low electrical resistance connection. Similarly, the pair of aerial feeder wires (usually 270mm²) each connect to a pair of U-bolt parallel feeder clamps (with machined flat mating surface) which are then firmly connected to the copper plate, again providing a very low resistance connection.
- The plate can handle the large *mechanical stresses* when the stiff terminating cables and long aerial feeder wires make their connection to the plate. Without the plate (mounted on a solid post type insulator), it would be difficult to terminate the cables to the aerial feeders in a way that ensures the minimum 150mm electrical clearance to earth is always achieved.
- The post type insulator that supports the plate delivers the required 150mm minimum electrical clearance from live to earthed structure (provided the various attachment bolts and other hardware don't encroach this clearance).
- The plate can allow the cables to come in at 3 distinct positions (90°, 180° and 270° to the plate axis), and the aerial feeders at the other end can take off in 3 directions (as above).
- The large size of the plate means that any heat generated at the resistive connections, when passing heavy current, can more readily be conducted to the rest of the plate and cooled by means of radiation and heat convection.

CABLE LUGS

The cable lug tube is inserted over the bared-back copper conductor core of the cable and crimped under high pressure to give a very effective mechanical and electrical connection, both aspects of which are vital in this connection.

Cable lugs are not suited to terminating onto hard-drawn copper strands. See *Section 3.7.0.5, Crimp Lug Connection of HDBC Wire* for more details.

CABLE SURGE PROTECTION

The cables are protected against lightning surges with a *surge arrester* installed in close proximity. I understand that the surge arrester called up in *Figure 449* is rated at 20kA.

As explained later in *Section 3.9.0.5, Length of Connecting Leads (Wires)*, it is important that the lead length, connecting the surge arrester to the 1500V cable, be made as short as is practical in order to minimise its inductive voltage drop (due to the high frequency lightning surge current) and thus provide an effective voltage "clamp" across the vulnerable cable insulation.

If the cable insulation fails, the cable will need to be replaced urgently, which is a very expensive and inconvenient thing to have to do, and could take some time to affect repair.

CABLE TERMINATION KIT

The proper termination of the 1500V XLPE cable into a lug requires the use of a commercially-available "cable termination kit". Refer to Item 15 in *Figure 449*.

This kit includes a special (heatshrink or other) sleeve and other parts which, after following the approved installation method, provides a means of ensuring that ***no moisture can enter the cable***, which would otherwise destroy its XLPE insulation (in the short or long term). It also provides appropriate voltage stress distribution from core to screen. And it comes with corrugations or "skirts" that increase the current leakage path across the cable from live (lug) to dead (cable screen) during rain or foggy conditions.

CABLE MECHANICAL PROTECTION

The 1500V cable itself may need to be protected, especially near the ground, from collision damage by vehicles.

This risk should be assessed and suitable bollards, barriers or other effective mechanisms put in place to prevent such damage.

ANTI-CLIMBING MECHANISMS

In some situations, there's an increased risk of someone climbing the feeder structure. In such cases, "Anti-Climbing" mechanisms need to be installed to prevent people from gaining access to the feeding arrangement with its exposed live parts and other hazards.

Anti-climbing mechanisms can include one or more of the following:

- A metal "access prevention grill" that bars access. This usually comprises a series of galvanised steel rods with sharp ends that radiate out from the structure. It's installed on the portal / mast leg and/or on the portal bridge (at one or both ends). These are an obvious deterrent to would-be offenders, but care should be given to ensure that the sharp end of the rods don't somehow themselves become a safety hazard. Refer to *Figure 451*, which has 2 grills on this side of the structure.

Figure 451 - Access Prevention Grills

- A solid sheet metal shroud covering the lower area of the feeder mast with cables installed, up to a certain height. I guess this idea relies on the sheet metal being slippery, and with no footholds there's less chance of a person gaining purchase to climb the mast to higher levels. (I don't think I have ever used this method.)
- Fencing, gates and/or other types of larger barriers that prevent people getting anywhere near the structure.

DIFFERENT FEEDING SCENARIOS

Appendix "B" – Switching & Feeding Situations shows several feeding scenarios in diagrammatic form.

It is most important to refer to the current Standards regarding the earthing specifics of each situation (as the approaches may change over time).

Earthing of the cable feeding arrangement plays an important role in a successful design. The specifics of earthing design for each situation should be carried out by those with Engineering Authority to do so, with the resulting design drawings signed-off by such persons. Unusual situations may require help and sign-off from a higher level.

EXAMPLE OF TYPICAL FEEDING ARRANGEMENT

Figure 452 is a photo of a recent cable-to-aerial feeding arrangement installed on a portal structure.

I thought this would be a good example of such an arrangement, but have just noticed that the potential jumper (PJ), which connects the anchor pennant wire to the main catenary wire, appears to be a standard feeding jumper (FJ) instead. A potential jumper is simply a 90mm² copper wire (not the 270mm² size shown), that electrically connects the anchor wire to the main OHW so that it remains at the same electrical potential. There should never be any

significant current flowing through the potential jumper (thus the need for only a small CSA size). There is also no need to connect down to the OOR contact wires, as their potential is achieved through an in-span feeder in the anchor bay itself.

But the rest of the arrangement seems OK, and it gives an idea of how much copper is needed to feed the 2 different electrical sections.

"Section 1" is fed by twin 270mm² HDBC wires to the *tail* of the catenary, and "Section 2" is fed to a catenary *feeding loop* formed across a K-Line insulator.

See also *Figure 455* for identification of other parts of this feeding arrangement.

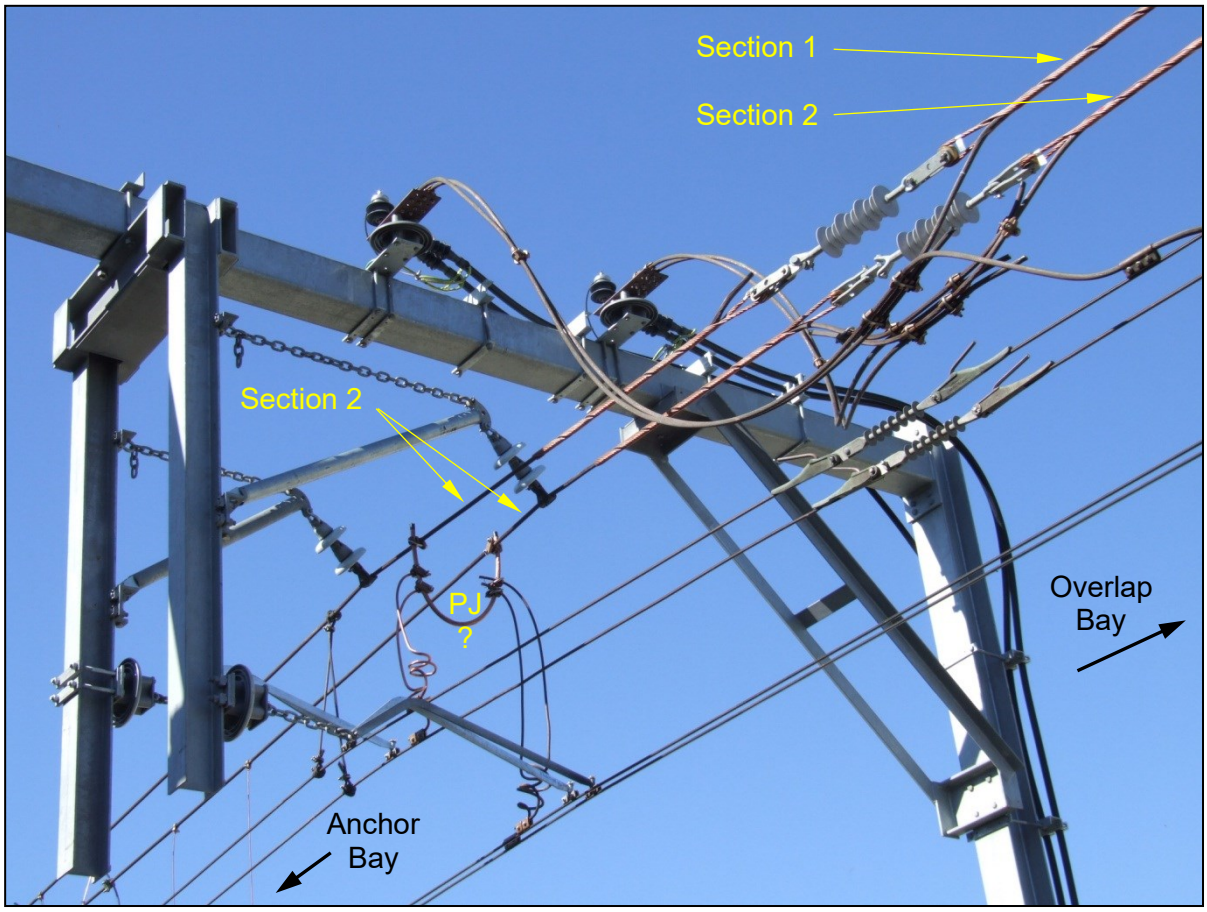


Figure 452 - Typical Cable-to-Aerial Feeding with Surge Arresters protecting cables

3.8.0.6 Status (c. 2014)

Cable feeding is the preferred method of connecting from substation or sectioning hut to the OHW (with a short aerial feed from the cable-to-aerial termination to connect to the OHW itself).

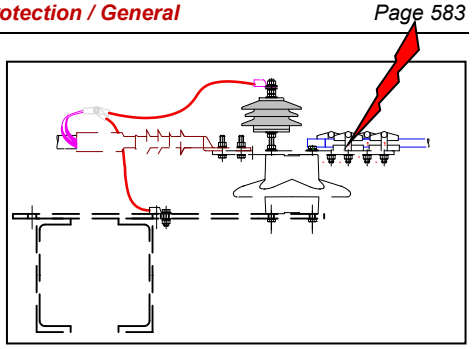
The alternative long aerial feeds are unlikely to be accepted in any future new arrangements, unless suitable risk assessments are carried out and approved on specific proposals.

Cable feeders are far more desirable in terms of minimising the risks. However, this option is initially more expensive than aerial feeders, and all the cables need to be protected from lightning surges and other potential causes of damage (such as vehicle collision).

3.8.0.7 Reference

See *Table 39* for drawing reference.

3.9 SURGE PROTECTION



3.9.0 General

3.9.0.1 Description

Surge protection of certain OHW equipment against lightning surges is achieved using "surge arresters" for OHW (or "surge diverters" as they used to be called).

Surge arresters look much like insulators, and for most of the time, just like insulators, there's almost an open circuit between both terminal ends. But when a lightning surge appears at this device, the open circuit becomes a short circuit. This allows heavy current to pass and importantly, it clamps the voltage across these terminals which can then protect the OHW equipment connected to it against over-voltages.

These devices are usually installed:

- At the track-end of 1500V cables feeding the OHW (on the cable-to-aerial termination arrangement – shown in the above diagram). This is their prime location these days.
- At aerial feeders to OHW from some substations and sectioning huts (although this may be classed as substation equipment).

Surge arresters used to be connected to the OHW midway between substations and sectioning huts, and at dead-end tracks remote from supply points. However, they were deemed ineffective in these situations and therefore may no longer be used in these situations.

(Photo courtesy of the Internet – photographer unknown)

3.9.0.2 Function

In the 1500V OHW system, the greatest threat from a high voltage surge on the OHW originates from lightning, either in the form of a direct strike on the wire, or a strike nearby (an indirect strike) that's then induced into the OHW. Half the current from the lightning strike flows in each of the 2 directions away from the strike point on the catenary.

A surge arrester connects across the equipment being protected, such as a 1500V cable. *Figure 449* (further back) is indicative of the standard arrangement for typical recent applications.

Referring to *Figure 453*, a surge arrester helps protect the equipment being protected (the 1500V cables) by providing the following 2 crucial functions:

1. In terms of ***Voltage***:
It prevents the high-level lightning impulse voltages from flashing over at or within the equipment being protected which, namely for OHW, is the insulation on 1500V cables. The surge arrester is a virtual open circuit for voltages up to some threshold above the operating voltage but well below the breakdown voltage of the cable insulation being protected, e.g. 2.0kV.
Voltages above this cause the surge arrester to become a short circuit to protect the asset.
Note that the *length* of the lead wire/s from the surge arrester to the protected equipment plays a vital role in effectively clamping this voltage – the shorter the lead length, the better the overvoltage protection and the better the outcome.

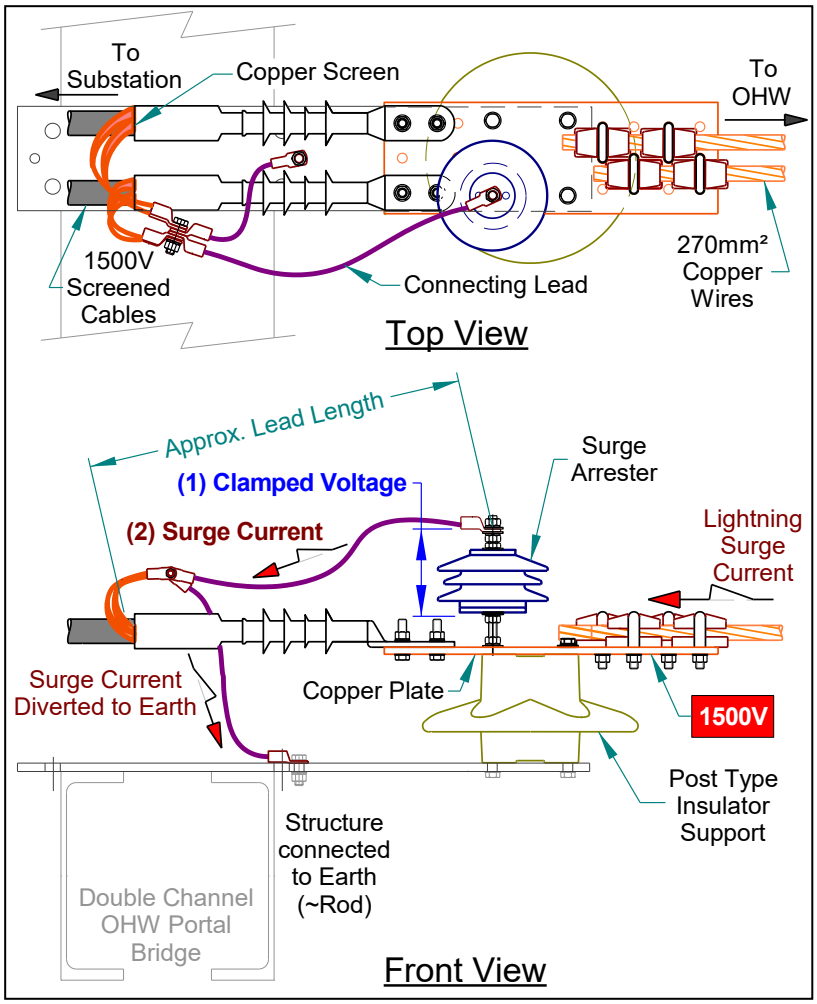


Figure 453 - Surge Arrester protection of 1500V Cables

2. In terms of ***Current***:
When lightning strikes the OHW, a surge arrester also diverts the heavy lightning current surge (of the order of 20,000 Amps or so) down to earth, thereby helping to minimise any surge propagation and any consequent lightning current damage nearby in the OHW system.

3.9.0.3 Typical Components

The following components are common to most surge arrester arrangements:

- The *surge arrester* device. See *Figure 454* for an example of an approved surge arrester.
- *Mounting hardware* to allow appropriate support of the surge arrester unit.
- Copper *connecting lead/s*. The leads can be on both the earth side and the live side of the surge arrester.
- *Earthing cable*. The surge should be conducted to earth (ground) as directly as is practical, and this usually requires an earth cable (usually 70mm² or more recently 95mm² copper, with green/yellow insulation covering).

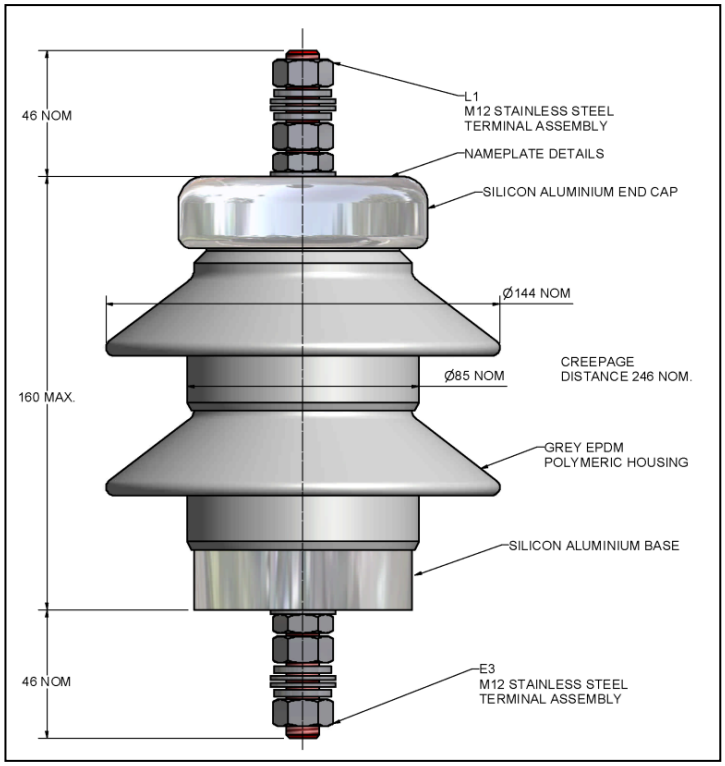


Figure 454 - Example of Surge Arrester (ABB)

- *Earth rod*. This long metal rod (e.g. hard-drawn copper) is driven deep into the ground to provide a solid earth connection for the bottom end of the earthing cable to terminate on. The small exposed length at the top of the rod where the connection is made, is normally protected from inadvertent damage by a concrete pot with lid (or similar).
- *Cleats*. These metal brackets, spaced up to 1,000mm apart, clamp around the earth cable and fasten it to the OHW structure on its path down the OHW structure to ground.

3.9.0.4 Configuration

One or 2 copper leads (of relatively small diameter) connect the surge arrester to the equipment being protected. The length of these leads needs to be kept as short as practical to ensure that their finite inductance does not diminish the surge arrester's effectiveness at clamping the voltage across the equipment being protected (see *Section 3.9.0.5* further below for more details).

Surge arrester arrangements are normally installed at the following OHW situations:

- ***Cable feeding locations (at the OHW feeder structure)*** – A surge arrester is installed to protect the 1500V cables (designated as 3.8/6.6kV) from suffering insulation damage due to lightning surges. The cable feed to the OHW is normally achieved using 2 (or sometimes 3) 400mm² cables in parallel. One surge arrester can protect many cables in parallel. It's installed electrically between the cable core and its metal screen, and with as short a lead length as is practical.
  This scenario also includes locations where 1500V cables have been used to connect local 1500V sectioning switches to OHW.
  The design for these situations is performed by the OHW designer.
- ***Cable feeding locations (at Substations or Sectioning Huts)*** - Ideally the substation or sectioning hut end of a 1500V cable run to the OHW should also have some over-voltage protection installed. This is because any remaining (clamped) surge voltage passing from the OHW end through the cable, can be reflected as double this voltage at the S/S or S/H end of the cables. So, a surge arrester installed here can again help to limit any over-voltage and so protect the cable insulation.

This surge arrester is usually designed as part of the Substation or Sectioning Hut design, not the OHW design. (This additional surge arrester may not be absolutely necessary for short cable runs – a Standards issue.)

- ***Aerial feeding locations from Substations or Sectioning Huts*** – A surge arrester will likely be installed on the aerial feeder as it enters a Substation or Sectioning Hut, to limit the amount of surge passing into the more delicate electrical and electronic equipment located inside the confines of the S/S or S/H.
  This surge arrester is usually designed as part of the Substation or Sectioning Hut design, not the OHW design.

Figure 449 (further back) shows the standard *cable-to-aerial termination* arrangement (fitting 468/51), and it includes a surge arrester (Item 18) mounted on a copper plate. The other (top) end of the surge arrester has a 42mm² copper lead that connects to the combined lug-connected cable screens. A 95mm² earth cable also connects at this main point. I understand that the surge arrester called up is rated at 20kA.

Note that the effective lead lengths are kept short, in fact mounting the surge arrester directly onto the copper plate helps provide the shortest "lead" possible in this arrangement (only 1 traditional lead is needed then).

Figure 455 is a photo of two typical cable feeding arrangements to the OHW as per the above cable-to-aerial termination arrangement drawing. (See also *Figure 444*.)

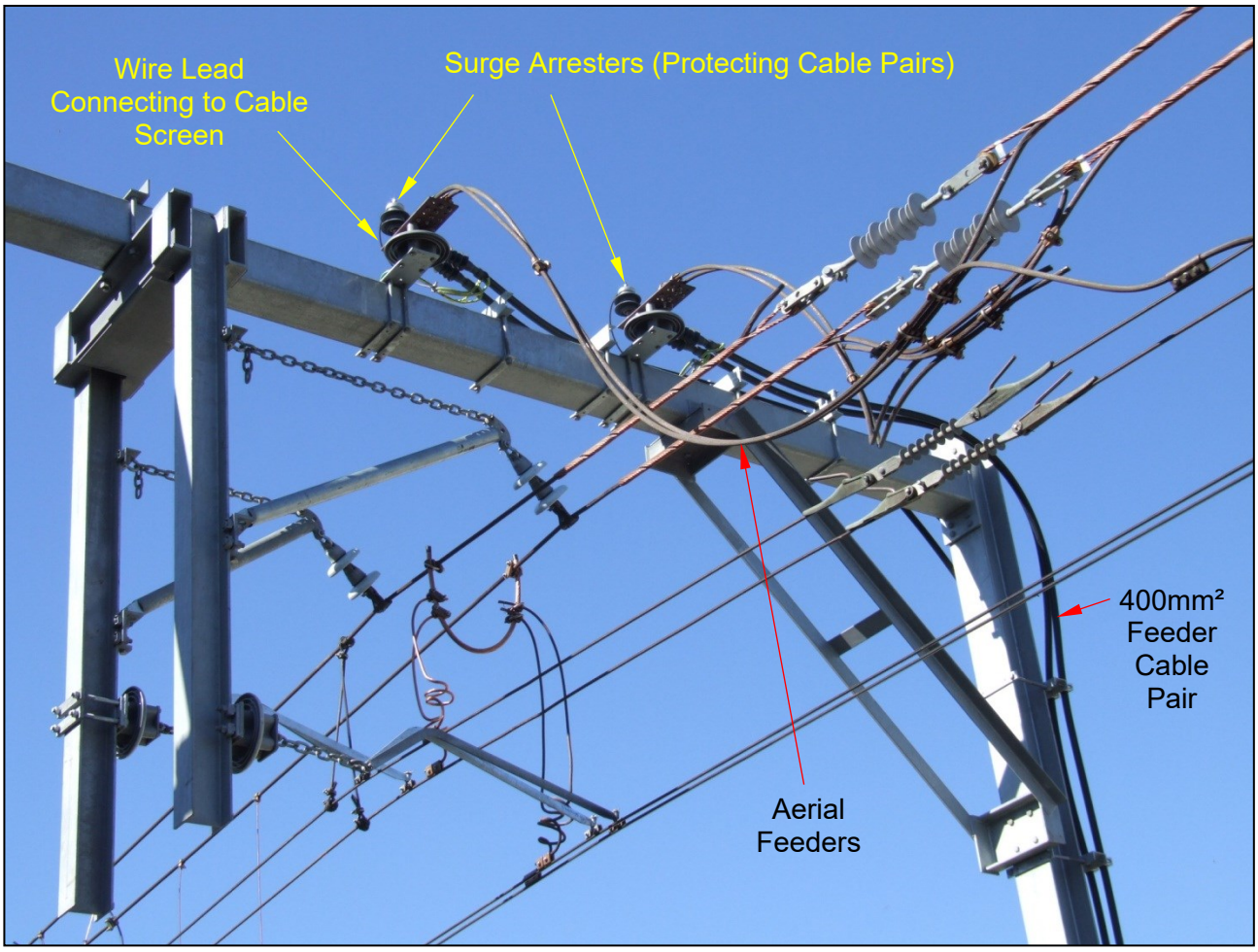


Figure 455 - Cable Feeding to OHW – Cables protected by Surge Arresters

TMP Code	Equipment Name	Made By	Drawing No.
EP-08-43-00-00	**Surge Arrester Arrangements**		
EP-08-43-01-00	*Surge Arrester Arrangement (General)*	*RailCorp / Various*	*EL0475906 B/83402 Sh. 2*

Table 40 - Surge Arresters

An earth lead usually connects the surge arrester to an earth stake driven into the ground for a nominated distance, according to its earthing design (this is needed for providing a good low earth resistance). The earth wire connection to the top of the earth rod is protected by a concrete pot and matching lid (for later access).

3.9.0.5 Design Notes

Refer to Standard EP-21000001-SP, "Insulation Coordination and Surge Arrester Selection". This standard (or specification) gives lots of useful information on surge protection for Sydney's traction network, regarding the high voltage ac infrastructure.

Residual Voltage

The surge arrester manufacturer publishes data on the "Residual Voltage" for a particular device and for a range of characteristic lightning current waveforms. For example, the surge arrester called up in *Figure 449* is their model "ABB POLIM-H 2.0 SD". For a 20kA impulse current, the residual voltage across this surge arrester is about 5kV. This residual voltage needs to be taken into account when selecting surge arresters for protecting the insulation on vulnerable assets – in the case of OHW, the 1500V XLPE screened cable.

The Character of Lightning

Lightning is unpredictable, and its path to earth can take on all sorts of direction changes, including travelling horizontally. So, even if lightning rods and other methods of attracting and controlling lightning are installed, there is absolutely no guarantee that they will always be effective. That's nature for you. But they are definitely worth pursuing as they can decrease the *likelihood* of a strike, and possibly the *severity* of damage should it strike.

Apparently the conductive column of *plasma* in a bolt of lightning can be almost as narrow as the width of a pencil, and can reach temperatures well above those on the surface of the sun. The column appears thicker because it's extremely bright.

The oddest thing is that, in most cases, just before a bolt of lightning approaches the earth, a smaller (weaker) return stroke heads up from the ground to meet it, thus forming the solid earth strike. And there are often several strikes following this path in quick succession.

Depending on how the lightning strike occurs, its current can vary enormously, and can typically be anywhere between about 5,000 amps and 200,000 amps.

A typical stroke has some 1,000GWatts of power, and is transferred in a fraction of a second.

The current pulse in a lightning strike is variable, but can typically last around 50msec or so, but can have an extremely rapid initial rate-of-rise time of about 1.2 µSec. (The standard lightning waveform is 1.2 / 50µsec – 1.2 µSec to rise and 50 µSec to decay to half value).

LENGTH OF CONNECTING LEADS (WIRES)

This is important – the connection of the surge arrester to the equipment being protected (usually 1500V cable) should be done ***with the minimum practical wire lengths*** (called "leads"). This includes leads to both sides of the surge arrester.

The rapid rise of current ($\frac{dI}{dt}$) along the surge arrester connecting leads (wires), due to their small but finite *inductance* (L), results in a voltage drop (V) across the inductive lead of $V = L \frac{dI}{dt}$.

This voltage drop in the leads reduces the "voltage clamping" ability of the surge arrester. And the shorter the lead length the less voltage drop.

The old "rule of thumb" used to be that the protection is reduced by about 5kV for every metre of lead length (or in the old imperial scheme "1.6kV per foot"). So, if the cable has a nominal rating of 3.8/6.6kV, then it doesn't take much lead length to render the surge arrester ineffective against clamping lightning impulse voltages, and damaged insulation can result. If the special cable insulation is damaged, the cable is likely to short circuit, which then trips the DCCB protection and stops trains – possibly for a very long time.

As mentioned above, surge arresters used to be installed midway between substations and sectioning huts, and at the ends of certain terminating roads remote from the supply point. In fact, one can be seen with its long lead connecting to the catenary wire further on in *Figure 213* if you look hard enough. The theory used to be that a surge arrester installed onto the OHW about half way between substations and sectioning huts had the potential of reducing the likelihood of a flashover on the OHW equipment, and also could reduce the surge current/voltage that would otherwise continue to the vulnerable feeding locations.

However, in the 1990s, surge arresters were deemed ineffective in this situation as the lead length from surge arrester to OHW was so long that the huge voltage drop across this lead could allow the surge to potentially flashover the primary insulation it is trying to protect. [The lead length would normally be about 3.5m, which means a voltage drop of about 18kV – well above the 1.5kV nominal system voltage.) The best that could be hoped for was to help earth some of the surge current that would otherwise continue along the OHW to the nearest Substation or Sectioning Hut, which is at least something I guess (?).]

Indeed, having these surge arresters installed midway did pose the risk of a potential problem – if the device itself became defective and "shorted out", then the 1500V line voltage could be directed to earth via the surge arrester earth wire. More importantly, if the earth wire then became disconnected from earth near ground, this could pose an extreme safety hazard if someone were to touch the lead, or if the lead were to touch other nearby metallic objects. Unfortunately, unless there's an extremely large current flowing as a result (typically > 6,000Amps or so), the DCCBs will not trip to isolate the hazard, and so the earth wire could remain alive at 1500V!

Since the removal of surge arresters from midway points, to my knowledge there has not been any obvious detriment to the system.

LIGHTNING PATH TO EARTH

The nature of lightning current travelling down an earth wire or cable is that it seems to prefer to travel in straight lines. So, if there's a sudden 90° bend in the wire (going from vertical to horizontal say), the lightning may choose to instead take a diagonal short cut and flash over before reaching the bend, damaging the wire and any covering insulation in the process.

So, straight or gently curved paths are preferred when designing and constructing earthing arrangements for surge protection. This is probably more important when earth wire is installed on timber poles, because the timber is an insulator and the surge is more likely to

keep to the earth wire, whereas the surge may take an alternate conductive path if installed on a steel mast (for instance).

If specific OHW structures need to be solidly earthed because of surge arresters protecting 1500V cables (with their screens connected to the structure), then the earthing details of the structure are shown on drawing EL0001334. Note however that the current standards must be referred to, since the approach may have changed and any altered requirements need to be adhered to (that is, assuming this drawing isn't also updated).

3.9.0.6 Status (c. 2014)

Surge arresters are no longer installed midway between substations and sectioning huts, nor at the end of various terminating roads.

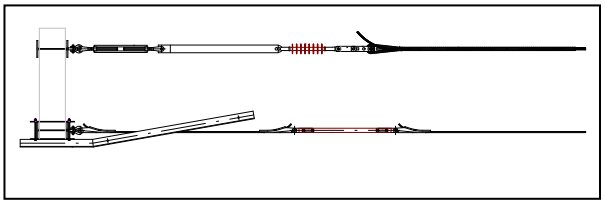
Surge arresters are not to be installed on the catenary anchor bridle wire at regulated mid-point anchor locations. (The mid-point anchor bridle can span 60 metres or more and becomes an integral part of the surge arrester lead length – it thus has a large voltage loss and provides unacceptable protection.)

Because of significant failures from the Bowthorpe surge arrester, it is no longer installed into the OHW system. (There had been problems, and one of these units failed only a couple of months after being installed on a crucial new 7-switch structure located at North Sydney, which was designed for quick isolation of the OHW sections near the Sydney Harbour Bridge in an emergency. The consequential disruption to services and passengers was immense, which was absolutely counterproductive.)

3.9.0.7 Reference

See *Table 40* for drawing reference.

3.10 OVER-RUN PROTECTION



3.10.0 General

In this document, the term "over-run" has to do with raised pantographs on a train venturing into a track where the contact wire is missing at some point, and so it can no longer control the height of the pantograph/s.

3.10.0.1 Description

Over-run protection equipment is commonly installed at the entrance to car maintenance sheds, and at the start of some spur tracks, etc.

3.10.0.2 Function

Over-run protection can help control pantographs in situations where a train ventures into an unwired section of track with its pantographs inadvertently (or otherwise) *raised*. In such situations, the pantograph may damage the OHW and other infrastructure if its height rises to full extent (in an uncontrolled manner). And if the mistake is noted and the train then ventures back with this high pantograph head ... (oops).

There are 2 approaches:

a) The over-run protection equipment is designed with "skids" to allow the pantograph to proceed in a way that eventually lets its height to fully extend without damaging other infrastructure.

b) The over-run scheme may simply provide some basic OHW for a short distance (typically a *short run of contact only OHW*) to control the pantograph, so that the train can proceed and be stopped by other means (such as a buffer stop).

The problem is that, unless a pantograph is lowered (pneumatically), if it's not restrained by a contact wire, it will rise to its full height, likely leading to a number of adverse consequences.

3.10.0.3 Typical Components

The following components are somewhat common to most over-run protection arrangements.

SKIDS

These are long metal devices designed to allow a slowly approaching raised pantograph to slide along its underside and subsequently control the pantograph's level in some way.

This typically involves the skids forcing the pantograph down a little (to clear other hardware), then eventually causing the pantograph to rise freely (to its upper height limit) as the train proceeds beyond the skid. In this way it minimises the risk of any damage to the raised pantograph.

INSULATORS

Terminal insulators are required to terminate the high mechanical tensions of catenary and/or contact wires that lead to the skid arrangement.

Sometimes a contact insulator is required to have characteristics that allow a pantograph to slide along it, as shown in *Figure 456*. The pair of permali beams and accompanying half-

splices from a Type 5 section insulator have been used in the past for this purpose, although the challenge here is to keep the beams flat (i.e. not axially rotated). Wear to the underside of these insulators may be an issue over time, depending on how many pantographs actually use it.

SECTION INSULATORS

Section insulators, or parts thereof, are sometimes needed to help provide a "neutral zone" (floating section) in the OHW in advance of the skid. Refer to *Figure 458* for example.

3.10.0.4 Configuration

As mentioned above, there seem to be a few situations that require some form of the following over-run protection:

- *Skid Arrangement*
- *Short Contact Run*

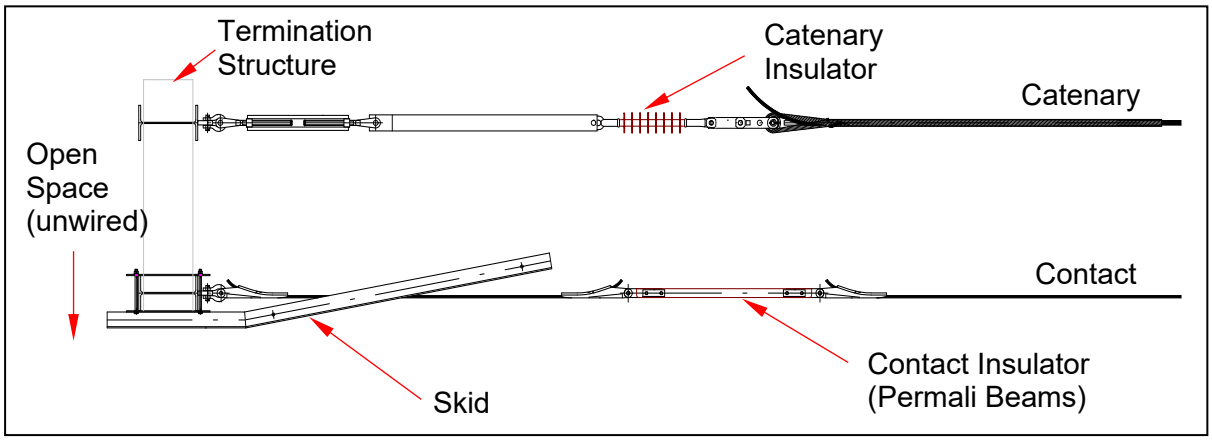


Figure 456 - View of typical Over-Run Protection Skid arrangement

SKID ARRANGEMENT

The most typical form of over-run protection is the "skid" arrangement, which can occur at car sheds. See *Figure 456* for such an arrangement. Within the shed, workers can gain access to the top of the train without any OHW passing inside and the physical and electrical hazards thereof. Ideally, the pantograph should be completely lowered before entry to the shed.

Should an electric train proceed into this area, most over-run skid arrangements are configured to allow an inadvertently raised pantograph to rise unimpeded into unwired space without causing damage to the OHW or to the pantograph. It is imperative that the train does not then reverse its direction with any of its pantographs freely extended, as this will do considerable damage to the OHW and pantograph.

This type of situation usually involves the establishment of a short "neutral zone" (isolated section) which is located in between the live 1500V section and the "earthed" or "rail-connected" section leading into the shed itself (as required by the site-specific "Earthing & Bonding" design of that shed). Refer to *Figure 458* for example. Note that this is one of the few situations where OHW conductors can be at a floating potential.

The provision of a neutral zone is required to prevent the associated DCCB from tripping if the pantograph progresses from the live section towards the earthed or rail-connected skid at the shed itself. Consequently, there should be little or no arcing during this transition through the neutral zone.

Figure 457 is a photo of an actual instance of the implementation of *Figure 458*.

TMP Code	Equipment Name	Made By	Drawing No.
EP-08-46-00-00	**Over-run Protection Arrangements**		
EP-08-46-01-00	*Skids*	*RailCorp*	*D/79599*

Table 41 - Over-Run Protection arrangements

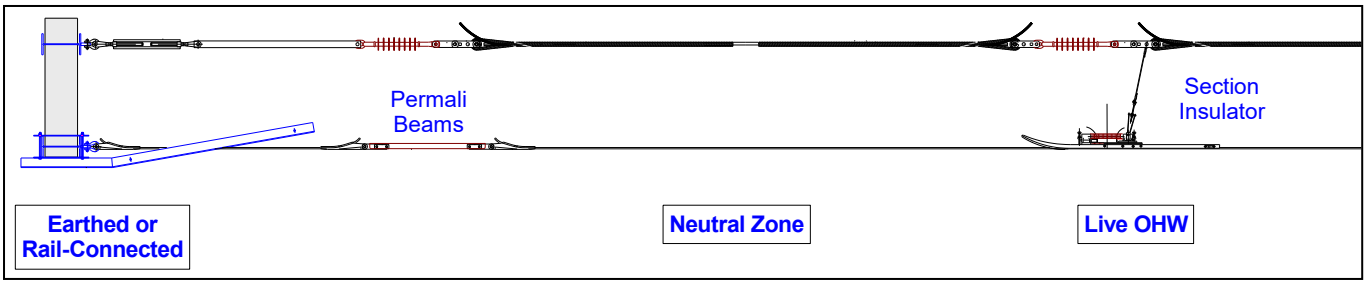


Figure 458 - Over-Run Protection with Neutral Zone

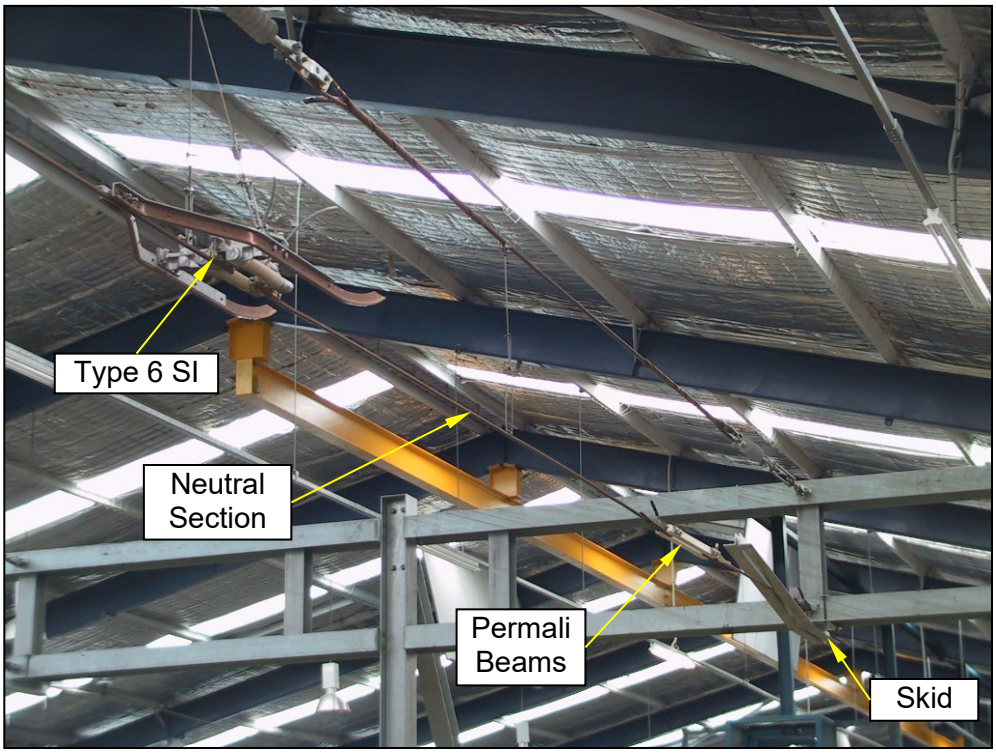


Figure 457 - Typical Skid arrangement inside Maintenance Depot

Figure 459 shows an instance where the contact wire is terminated onto a skid arrangement at either rail or earth potential (depending on the design for that situation). Note that there is no catenary wire. This is quite similar to the lower portion of *Figure 458*.

Figure 459 - Skid at entrance to Car Shed

This allows a pantograph, if unintentionally raised, to be well controlled before entering the shed. Inside the shed the pantograph would then rise unimpeded to its full height (hopefully without causing damage). The far end of the skid in the photo is likely to be supported from the shed using a low voltage insulator located above the skid.

SHORT CONTACT RUN

There are situations where there is insufficient space or it's impractical to install a skid arrangement with an isolation zone – the raised pantographs just need to be controlled in some manner should the train venture into an unwired track.

A short contact wire run, which is electrically connected to the main OHW, can be installed over a turnout to an otherwise unwired track, in case a train decides to venture into that track. The short contact run can control the raised pantograph to an area past the main OHW, whence either the pantograph can then rise fully without damaging the main OHW, or the train stops. However, pantographs ideally should be fully lowered when reversing back out into the main track.

A good example is at the north end of Platform 23 at Central Station. Refer to *Figure 460*. When the Airport Line was being built it was decided that Platform 23 needed to allow for bi-directional train running. Normal running was in the southern direction towards the Airport Tunnels (the Down track). But there might be times when trains need to head north in the Up direction, back into the station. (*Note:* I need to talk "north" and "south" here because this area is where the 0km OHW reference for the Electrified Network is located.)

For this bi-directional scheme to take place safely, there needed to be a special turnout installed to prevent trains venturing further north and possibly colliding with trains on a common track heading south into Platform 22 (the main track divides into 2 tracks that service both Platforms 22 and 23). This special turnout is, I understand, under signals control, and it leads to a buffer stop a short distance away. If a train should ever use this turnout then there needed to be some OHW to control the height of the pantograph and minimise any resulting damage. (An alternative "skid" arrangement was deemed inappropriate.)

The over-run protection here is simply a short length of regulated contact-only OHW (it's regulated because the main OHW was recently regulated). Its only job is to properly control the pantograph (especially uplift) as it heads into this short turnout track.

Any damage in this crucial area of the network could have a huge impact on train running, so it was important that this situation be properly controlled in its many aspects.

Figure 460 - Over-Run Protection at Central Station (looking to north)

3.10.0.5 Design Notes

CONTACT PROFILE

When installing a *short contact run* for over-run protection, it is important that its contact wire is appropriately aligned – especially its height – with the main line wire. This is so that a smooth pantograph transition can take place, even at the extremes of temperature (if fixed-anchored).

Generally speaking, if the main line has fixed-anchored OHW, then the short contact run interfacing it should also be fixed-anchored. The take-over area should be located near a catenary support location (which provides minimal contact height fluctuations with temperature). Ideally the contact wires should cross each other (with main line contact under the contact run), and be knuckled together to further help keep the 2 wires together when undergoing any relative vertical movement with temperature and pantograph uplift.

Likewise, if the main line has regulated OHW, then the short contact run should be regulated. Ideally the contact wires should cross each other (with main line contact below the other) and with a sliding knuckled installed to help keep both wires vertically together.

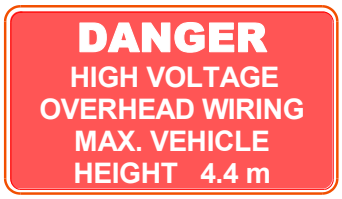
3.10.0.6 Status (c. 2014)

Developed as required.

3.10.0.7 Reference

See *Table 41* for drawing references.

3.11 SIGNS



3.11.0 General

3.11.0.1 Description

Signs are generally made on aluminium or steel plate and consist of lettering or symbols on a contrasting background colour. There are a variety of signs pertaining to the overhead wiring system.

3.11.0.2 Function

Signs convey visual information. Some signs warn of a hazard (particularly relating to the lethal 1500 volt potential), while others relate some locality or operational information.

3.11.0.3 Typical Components

The only significant components are the sign itself and its method of attachment.

The sign would normally be made from sheet aluminium of a suitably robust thickness consistent with its overall dimensions. Some older signs were made from cast iron or cast aluminium, with the text embossed in the casting itself. These days sheet aluminium would be preferred, probably because of cost and ease of production.

There are standards regarding the wording of the signs, including the colours of the text and background, and the text sizes to be used. The location of the signs is also stipulated.

The method of fastening is usually by set screws and nuts, or by some form of silicone adhesive that can cope without breaking down over time, from exposure to UV light, moisture, the heat and the cold in an external environment.

3.11.0.4 Configuration

Signs can be fundamentally categorised into 2 types:

- *Safety Signs* – These signs generally convey messages that warn of a condition which, if breached, could result in an unsafe or lethal situation.
  Note however, that some signs may not appear to be safety signs as such (due to their passive wording), but the information they convey is absolutely vital to the safe operation of the electrical network, and so they ought to be treated as safety signs.
  A good example is a sign that displays electrical sectioning numbers at OHW switches – the information they display – electrical sectioning number/s – *must* be kept up to date.
- *Non-safety Signs* – These signs simply convey information relevant to the situation, which generally is not directly of a safety nature.

Table 42 lists most of the signs relating to overhead wiring.

For safety-related signs, it is vital that they be kept in good visual condition, and that the information they contain is updated as soon as any relevant changes are made, e.g. changed electrical sectioning numbers, height clearances at level crossings, etc.

TMP Code	Equipment Name	Made By	Drawing No.
EP-08-51-00-00	**Signs**		E/89045
EP-08-51-11-00	*Level Crossings*		
EP-08-51-12-00	*Goods Yards*		
EP-08-51-13-00	*Goods Sidings*		
EP-08-51-14-00	*Structure Identification*		*D/86098*
EP-08-51-15-00	*Switch Identification*		
EP-08-51-16-00	*Wood Pole Rail-Connection Warning Sign*		
EP-08-51-17-00	*1500V Cable Warning Plaque*		
EP-08-51-18-00	*Electric Train Stop Boards*		
EP-08-51-19-00	*Feeder Mast Spark Gap Sign*		*E/88294*
EP-08-51-20-00	*Unwired Siding*		

Table 42 - Signs

3.11.0.5 Design Notes

TYPES OF SIGNS

Some examples of common signs used these days for the OHW system include:

- ***OHW Structure Location Numbers (Mast Labels)***. These are intended to uniquely identify each OHW structure in the system, based on track route (the prefix letter/s) and *approximate* kilometrage from Sydney. They employ a "+" sign instead of a decimal point, to deliberately distinguish them from track kilometrages (which they definitely are not). See *Section 5.3.3* for more information in this.
  These signs should be considered a safety sign, as the information is used as a fundamental and unique reference for maintenance and operational activities, and must be kept in good condition for easy visual recognition.
  Example: "SL123+456"
  Refer Standard EP-08160001-SP, "Labels for OHW Structures".
- ***Switch Identification Signs (Labels)***. These are located at all local OHW switches, to advise of the specific electrical section and subsection of the individual switch.
  Refer to *Figure 461* for example. These have definite operational and safety implications as the correct electrical section/s must be identified before the switch is operated.
- ***Level Crossing Signs***. These obviously appear at level crossings, to warn drivers of the 1500V hazard and height restriction when passing underneath the OHW. All drivers of road vehicles need to be aware of the height restriction on their vehicle if passing through the crossing. The clearance should be such that there is at least 1,000mm of free space between the highest part of their vehicle and the lowest part of the live OHW conductors (usually the contact wire). The vehicle height restriction distance is shown on the sign.
  Figure 462 shows one such situation, but unfortunately here the driver of the truck went under anyway, resulting in damage to the load on the truck and to the OHW equipment (and it was apparently reported in the local news!).
  Refer to Standard EP-08000012-SP, "Level Crossings – OHW Clearance Requirements".

3.11.0.6 Status (c. 2014)

Signs of various types need to suit each situation requiring them.

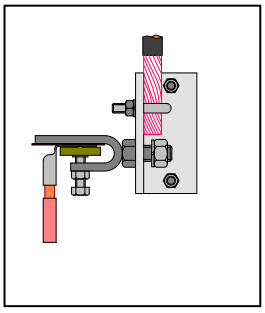
3.11.0.7 Reference

See *Table 42* for drawing reference.

Figure 461 - Switch Identification Signs (Labels) at North Sydney

Figure 462 - Example of Level Crossing Sign (likely ignored)

3.12 (BONDING)



This has been an awkward section to write about, because it does not seem to follow the same "equipment" structure as in previous sections of this chapter, and also because it's not easy to explain all that's going on.

I readily admit that I'm no expert in "Earthing and Bonding". It's a specialised area and so I may not always be absolutely correct in my interpretation or explanation, so in this regard *it is crucial to refer to the current standards* and other endorsed documents. But for what it's worth …

3.12.0 General

Bonding is associated with the 1500V *negative return* to substation, and generally involves connecting metallic structures which support, register or anchor the OHW, electrically to the *traction rail* of a nearby track. (The specific traction rail to use is identified by Signals staff as it can have safety implications.)

This section is mainly focused on some of the mechanisms that try to minimise the *risks* of a 1500V dc OHW system (with emphasis on the term "dc").

Three aspects in particular provide challenges to the safe and reliable operation of the OHW system:

- The reasonably high *voltage* (1500V) that the OHW conductors are energized at, coupled with the highly *exposed* nature of the multitude of runs of these conductors throughout the electrified network (although fortunately they are mostly constrained within the relatively controlled environment of the rail corridor, by track-side fencing, etc).
- The extremely *high currents* (up to thousands of amps) transferred through the OHW to supply Sydney's trains.
- The potentially corrosive nature of *dc* (direct current) if some of the traction return current passes back to the substation through the ground (rather than all of it flowing through the proper path through the rail/s of track/s).

Some risks are associated with the +ve 1500V (the OHW conductors) and others with the -ve 1500V (traction return through the tracks).

In 2013 I wrote a document called "North Sydney – Proposed OHW Bonding Policy" dated 14/7/2013. This document was in 2 parts – the first part generally described "bonding" principles and applications, and the second part went on to propose a bonding solution specifically for North Sydney Station. I have taken some of the information from the first part and included it here. However, the above document can provide much more detailed information on several approaches to bonding (as it applies to Sydney's OHW system).

Having said that, the approaches to bonding may change in time, so it is vital that *the current electrical standards be implemented* whenever undertaking any design work.

3.12.0.1 Description

The most obvious sign of bonding is a black insulated cable connecting between a certain mast, portal or other steelwork such as at overline bridges (any place that holds the OHW conductors through primary insulators), and the 1500V negative traction return rail (of adjacent track).

This bonding connection normally has a relatively small protective *spark gap* (SG) device connected in series, from the mast being protected, to traction rail. Electrically, this device is an open circuit, but it will permanently short circuit whenever a large voltage appears across the device (usually signalling that the mast it's connected to has livened up). In shorting out, the spark gap will solidly connect the mast to traction rail, in order to trip the DCCBs at nearby substations and/or sectioning huts and isolate the +1500V supply. The spark gap is typically bolted low down on the mast, which provides ready access for periodic inspection and testing of this device.

Sometimes several successive OHW structures are interconnected with either bonding cable or aerial bonding wire under tension and suspended between structures. They are then all electrically connected to a single spark gap and then to traction rail. This can save on the number of spark gaps needed (especially at railway stations), but it can sometimes be a challenge to find the fault if there's a problem with the circuit.

Prior to the 1990s, bonding was required on *all* OHW structures throughout the electrified network (with only a few specific exceptions).

However, in the 1990s a risk-based approach was adopted to bonding, in order to rationalise their usage (copper wire theft was an ongoing and costly problem). Now, bonding is most commonly found at overline bridges and on OHW structures at or near railway stations (where people gather), but it can also appear anywhere in the OHW system at locations deemed to have elevated risks. Refer to Standard EP-12200001-SP, "Bonding of Overhead Wiring Structures to Rail".

3.12.0.2 Function

There are several approaches to bonding, but the most common is described here.

Bonding an OHW structure, to the *traction return rail* of an adjacent track, is intended to protect that structure by offering a low resistance current return path in the unlikely event that the structure livens up to 1500V (for whatever reason). This should cause sufficient current to flow (of the order of several thousands of amps) in order to quickly trip the dc circuit breakers that feed that specific section of OHW, thus isolating the 1500V supply and rendering the situation safer. An immediate indication of each tripped dc circuit breaker (under supervisory indication and control from the Electrical Operating Centre), alerts staff of a problem which then needs to be resolved urgently in the field.

An OHW structure can liven up to 1500V if the primary insulation on that structure should somehow fail to insulate. (The insulators are in the OHW support & registration and/or anchor arrangements installed on that structure.) The structure can also liven up if the OHW conductors suddenly become electrically in touch with the structure, such as through a damaged pantograph, or tangled OHW, or some metallic object dropped or blown into the OHW at a structure location.

Unfortunately, in a dc system, bonding needs to also take into account the potential to cause excessive *stray dc currents* flowing through the ground back to the substation. This can cause *electrolysis corrosion* to certain parts of surrounding metallic services, including pipelines installed adjacent to the rail environment, and continuous steel reinforcing rods embedded in concrete, etc. (Note that an ac system does not have this same hazard.)

The steel rails of a track at any location will have a voltage, relative to earth, that varies all the time. This voltage is a complicated thing to calculate as it's dependent on several things, including:

- the train current drawn through the various tracks (with their rail resistances) by all nearby trains,

- the extent of distributed earthing of the rails resting on sleepers on the ground, and
- the distance from adjacent substations and sectioning huts.

This track voltage, if permanently bonded to a mast, can cause leakage currents (as described above) to flow back to the substation/s, which can also cause electrolysis corrosion over time.

So, a *spark gap* is normally included in series in the bonding circuit, as a trade-off in order to balance out the risks. It allows the structure to remain electrically isolated from the track (which helps prevent ongoing traction return leakage currents). But the device will short circuit if the structure livens up, and will then allow heavy fault current to pass so that the circuit breakers can "see" the fault and open accordingly.

Unfortunately, if a spark gap short circuits (for various reasons), there are no tell-tale signs of this, and so it will remain this way until it's tested and renewed. But in the meantime, this situation can allow the varying voltages on the track itself to drive dc leakage currents back to the nearby substations through the ground and potentially corrode any metallic services encountered along the way.

Note:

"Bonding" is definitely NOT "earthing" (although some people seem to think so). See *Section 3.12.0.5*, *Bond Wire is NOT Earth Wire*.

Bonding is primarily to do with ensuring that a dc circuit breaker can trip supply if a fault on the OHW system occurs that livens up some bonded metallic OHW structure.

Earthing is to do with connecting a metallic object to the general mass of earth, which is intended:

- To help reduce touch potentials,
- To trip ac protective equipment to isolate an electrical fault, and/or
- To divert a lightning surge to ground (in the case of a surge arrester).

3.12.0.3 Typical Components

Probably the most typical components of bonding circuits are shown on the simple standard "Bonding of Mast to Rail" arrangement drawing, shown in *Figure 464*.

The common fundamental components include:

Figure 463 - Spark Gap installed on a Mast

- A *spark gap*. This is a device that electrically isolates the bonded structure from traction rail, until the structure gets livened up, whence it becomes a short circuit (and remains so until replaced). *Figure 463* shows a spark gap installed on the web of a mast with its M20 threaded rod and nut.
- *Bonding cable*. This conductor normally has 95mm² copper cross-sectional area with black insulation. (In order to deter thieves, this was made with multi-strand steel wire instead of copper, over a period of time in the 1990s.) More recently, 120mm² multi-stranded copper cable has been used (as employed by Signals I understand), especially in cases of long runs to help reduce electrical circuit resistance.
- *Cleats*. Where the bonding cable rests against something solid like a steel beam or concrete wall, cleats are installed to regularly and firmly fasten the cable along its route. The usual maximum space between cleats is about 1,000mm. (The short length of bond wire between spark gap and traction rail will generally not be cleated.)
- *Cable lugs*. These proprietary items are used to terminate the copper cable and provide a substantial bolted connection to the structure.

- *U-bolt connection*. This is sometimes installed (instead of a lug connection) to provide a solid electrical and mechanical connection of the copper bonding wire to the structure being bonded. They are often used to connect horizontal safety screens to bonding wire.
- *Connection to rail*. The final connection to traction rail (or other) is provided and performed by signalling section. Sometimes this connection is provided at a signals impedance bond. (This overall approach is for safety concerns of the signalling system.)

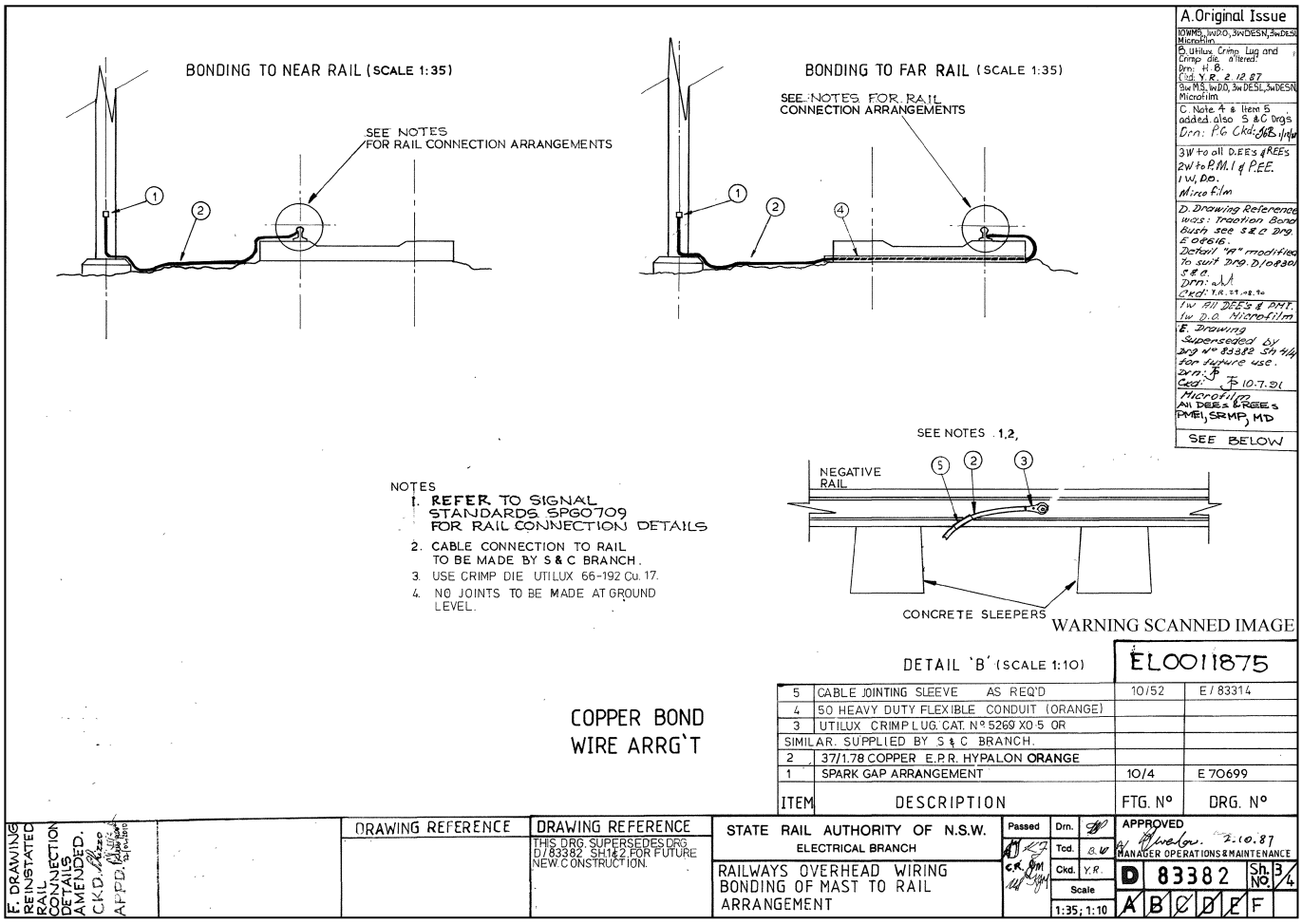

BONDING TO NEAR RAIL (SCALE 1:35)
SEE NOTES FOR RAIL CONNECTION ARRANGEMENTS
BONDING TO FAR RAIL (SCALE 1:35)
SEE NOTES FOR RAIL CONNECTION ARRANGEMENTS
A. Original Issue
NOTES
1. REFER TO SIGNAL STANDARDS SPG0709 FOR RAIL CONNECTION DETAILS
2. CABLE CONNECTION TO RAIL TO BE MADE BY S & C BRANCH.
3. USE CRIMP DIE UTILUX 66-192 Cu. 17.
4. NO JOINTS TO BE MADE AT GROUND LEVEL.
SEE NOTES 1,2,
NEGATIVE RAIL
CONCRETE SLEEPERS
DETAIL 'B' (SCALE 1:10)
WARNING SCANNED IMAGE
EL0011875
COPPER BOND WIRE ARRG'T
5 CABLE JOINTING SLEEVE AS REQ'D 10/52 E/83314
4 50 HEAVY DUTY FLEXIBLE CONDUIT (ORANGE)
3 UTILUX CRIMP LUG. CAT. N° 5269 X0.5 OR
SIMILAR. SUPPLIED BY S & C BRANCH.
2 37/1.78 COPPER E.P.R. HYPALON ORANGE
1 SPARK GAP ARRANGEMENT 10/4 E 70699
ITEM DESCRIPTION FTG. N° DRG. N°
F. DRAWING REINSTATED RAIL CONNECTION DETAILS AMENDED.
DRAWING REFERENCE
DRAWING REFERENCE
THIS DRG SUPERSEDES DRG D/83382 SH1&2 FOR FUTURE NEW CONSTRUCTION.
STATE RAIL AUTHORITY OF N.S.W.
ELECTRICAL BRANCH
RAILWAYS OVERHEAD WIRING BONDING OF MAST TO RAIL ARRANGEMENT
Passed
Drn.
Tcd.
Ckd.
Scale
1:35; 1:10
APPROVED
MANAGER OPERATIONS & MAINTENANCE
D 83382 Sh. No. 3/4
A B C D E F

Figure 464 - Standard Mast to Rail Bonding arrangement

3.12.0.4 Configuration

Refer to Standard EP-12200001-SP, "Bonding of Overhead Wiring Structures to Rail" for *prescribed locations* that require bonding. (Structures that do not require bonding are apparently to be fitted with a "DO NOT BOND" label, although this may have changed.)

According to the 2010 version of this standard, the overhead wiring structures satisfying the following location criteria need to be bonded to rail (the *prescribed locations*):

- Where passengers and/or the public are likely to contact the structure, including OHW structures at platforms and up to 10m beyond the ends of the platforms.
- Where staff normally board, alight from, or touch rolling stock whilst standing on the ground within 2m of an OHW structure (Goods Sidings, Yards & Maintenance Centres, etc).
- Where a 1500 volt switch is installed on the structure.
- Where important structures might otherwise be exposed to corrosion (e.g. bridges).
- Where signalling or other electrical equipment is mounted on the structure.
- Where structures are located in areas with potentially explosive atmospheres (e.g. coal and wheat loaders)

Figure 465 shows part of the bonding design drawing for a steel drop vertical (DV) that needed to be bonded at Epping Station. The bond wire is the thick black line in this drawing. The DV is insulated from any steel reinforcing in the concrete. This DV supports a Mark-3 Tunnel Cantilever arrangement (not shown). This is quite typical of the current type of fittings needed for a simple bonding arrangement, as described below.

The connection to the steel DV can be made using a stainless steel U-bolt (fitting 463/21) which compresses the copper bond wire directly to the steelwork (requiring 2 holes in the steelwork). Alternatively, a 95mm² tin-plated copper cable lug can be bolted to the structure. In either scenario, a solid connection is mandatory.

A lug should have a long barrel for multiple discrete crimps, so as to be both electrically and mechanically effective in this situation. In a way, the U-bolt is preferred, as it can give more confidence because you can see the copper wires being compressed by the U-bolt, and you can check for the tightness of the 2 associated nuts. Unfortunately, the integrity of the lug connection relies heavily on the installer correctly applying the crimps to the lug, and this may sometimes be a bit subjective.

The black 95mm² copper bonding cable is run along a suitable route from structure connection to the spark gap fitting. The cable is secured in place with a number of half-saddle (or full-saddle) clamps that wrap over the outside of the insulation of the bonding cable (without damaging this insulation), and they are fastened to the wall or structure. They usually have a regular spacing of no more than 1,000mm.

The situation may call for more cables to be run in parallel rather than just the one, in order to reduce the circuit resistance and in turn ensure the dc circuit breaker protection will reliably operate if and when needed.

Having a second bonding wire, ideally on a different route, may also provide for a level of redundancy if one of the cables happens to open circuit (for whatever reason). A bonding circuit using a "figure 8", providing several interconnected paths, may be even better in this regard. This approach has been used at a number of stations in the past, to interconnect several drop verticals together to a common spark gap.

In the engineering world, it seems everything has a risk associated with it. With bonding, there are risks of providing no protection, and there are risks with having the protection itself. The decision has to be made as to which risk gives the better overall outcome, in terms of:

- Safety (the ultimate goal),
- Adverse effect on other services,
- Reliability / operations,
- Cost (both initial & ongoing maintenance – testing, etc.).

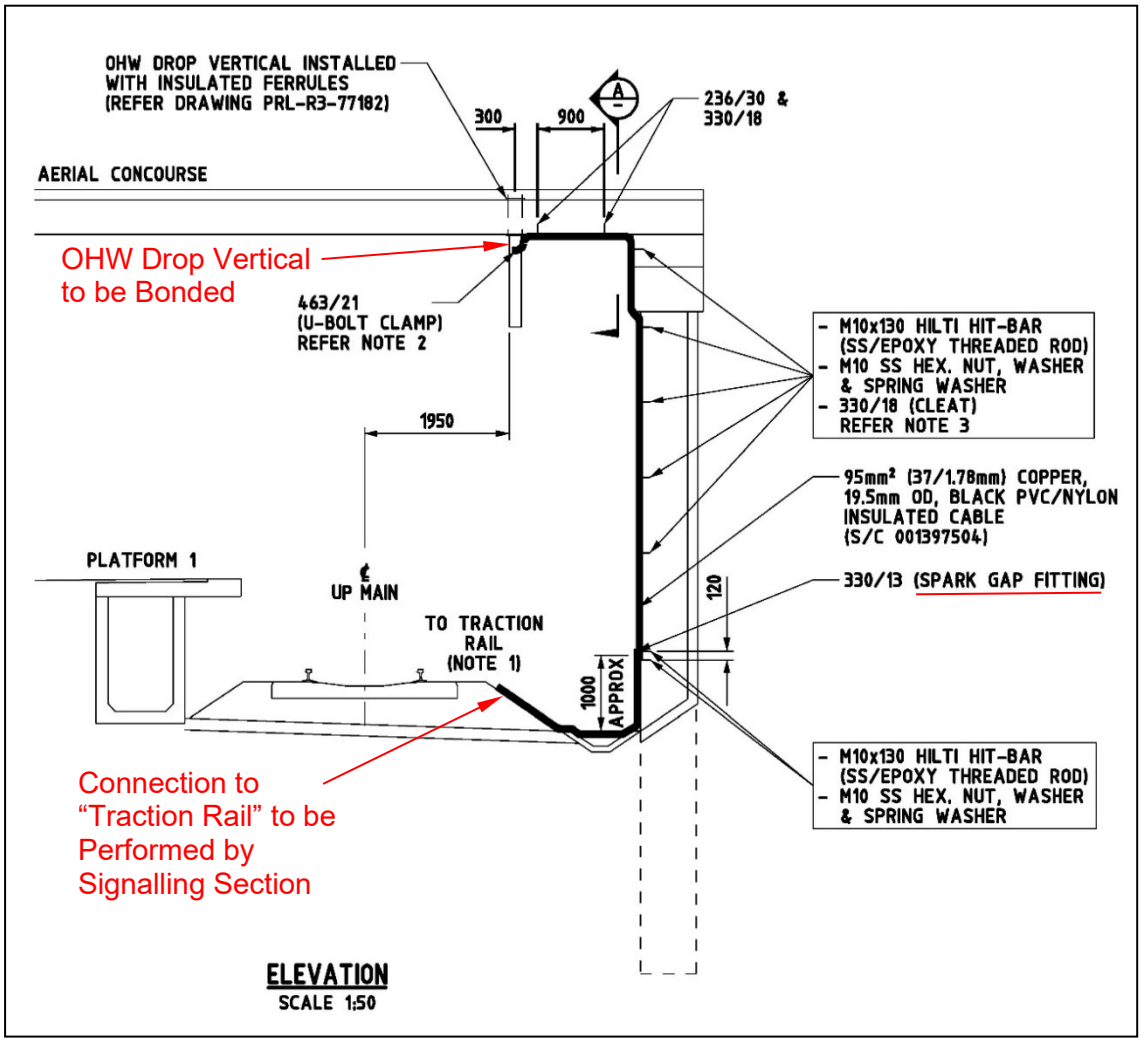


Figure 465 - Typical simple Bonding arrangement (Epping Station)

TMP Code	Equipment Name	Made By	Drawing No.
	Bonding		
	Copper Wire Bonding Arrangement to Mast		*D/83382 sheet 3*
	Steel Wire Bonding Arrangement to Mast		*D/83382 sheet 4*
	Bonding to Isolated masts (e.g. on Viaduct)		*C/89064*
	Bonding of Bridge Attachments - Typical Arrangement		*B/85797*

Table 43 - Typical older Bonding arrangements

3.12.0.5 Design Notes

THE TERM "BONDING"

In the electrical world, the generic term "bond" actually refers to a solid electrical connection (for passing heavy current).

In the 1500V dc system, the term "bonding" has a slightly different meaning – referring to the overall circuit that can help to protect the OHW and surrounding infrastructure in case a structure livens up (for whatever reason).

So, bonding often involves making more than one such *bond*, e.g. the simple bonding of mast to track using a spark gap involves:

- The spark gap device bolted (bonded) to the mast (with its M20 fastener), and
- The remote end of the bonding wire bolted (or welded) to the web of a track rail.

OHW Exposure Risks

A traction substation or sectioning hut has its various electrical equipment located within the confines of its building or fenced-off outside yard area. So, the operation of this equipment can be well controlled in this somewhat isolated environment.

However, the connected 1500V OHW system has a huge exposure to the outside world, as the various wire runs generally follow the associated train tracks which radiate away from substations for many kilometres.

The fact that the OHW conductors are located above the track, which itself runs through a "rail corridor", is fortunate as it gives the OHW some limited degree of controlled isolation and protection against the outside world (which at least is a better situation than that of the HV aerial lines that traverse all sorts of environments to interconnect the substations).

However, the increased risks (and associated consequences) due to the exposed nature of 1500V OHW are considerable. They include:

- OHW 1500V primary insulation failure, which can liven up the attached steel structure (mast, anchor, overline bridge, etc).
- Damaged train pantograph, which can bridge between live OHW conductors and steelwork (including masts, overline bridges, etc).
- Conductive objects dropped or blown into the OHW, e.g. metal roofing materials.
- Lightning strike (which is far greater for OHW than for substations, due to the sheer extend of exposure – many tens or hundreds of kilometres of wire compared to the land area of a large house for instance). This can cause failure of primary insulation and stop trains.

If a structure livens up (for whatever reason), it may remain this way unless the dc circuit breakers in the nearby substation and/or sectioning hut open, to isolate supply for that dc electrical section. These circuit breakers can quickly trip with either of 2 mechanisms:

- If they see sufficient fault current (e.g. more than 6,000 amps), or
- If the rate-of-rise of the fault current (measured in kA/ms) is rapid enough.

(The circuit breakers can also be opened remotely from the Electrical Operating Centre, but they would need to have a reason for doing so.)

Bonding such an OHW structure electrically to rail is a way of ensuring sufficient current flows to always trip the circuit breaker/s and isolate supply to that OHW section.

Bonding Tasks

Bonding, where installed, is in close proximity to the rest of the OHW system and is there for its electrical protection. So, it is often looked after by Mains staff, and because of this, it is an OHW design task.

However, this document does not deal with the actual negative connections from substation or sectioning hut to track-side impedance bonds – this is normally undertaken by the substation discipline.

Also, the signals discipline needs to be consulted, for they are responsible for making the actual bonding connection to the track (due to the risk of an improper connection affecting the signalling system).

Non-standard bonding designs need to be performed in collaboration with earthing and bonding experts, with appropriate sign-off.

TRACK INSULATION & RAIL VOLTS

In the open route, the track itself is electrically insulated from ground, either by timber sleepers or probably more effectively by concrete sleepers.

In certain areas, such as in some tunnels and on viaducts, the track can be laid on a concrete foundation (concrete slabs) and held in place using special "cologne egg" supports (or the like) instead of sleepers – these are intended to help reduce "noise & vibration" to sensitive surroundings, but they also offer good electrical resistance from track to ground.

The *rail voltage* at any location is a function of the current drawn by any nearby trains and the rail resistances back to the nearby substation/s. Consequently, its value at that location changes all the time, depending on the behaviour of the trains. (Note that its calculation can be quite complicated, as the various tracks in parallel are electrically tied together every so often in order to lower the overall track resistance, making the distributed current flow complex.)

This rail voltage seeks to return back to the voltage source (substation) by any means available, which is mostly through the steel rails, but it can also be through the earth and any other conductive objects located nearby that may provide a path. (The Rail Earth Contactor at a substation is normally open – the -ve 1500V is isolated from substation earth – in an attempt to minimise any tendency for return current to find and use these alternate paths.)

So, the electrical insulation provided under the rails of tracks helps to limit any tendency to leak current into the ground in the first place – to minimise *stray current* flow.

If the insulation of the sleepers is poor, e.g. they are buried in the ground, then low level dc stray currents can flow from rail into the ground and back to the substation (particularly in wet conditions).

Aside:

> Note that, while tracks resting on poor ballast is mostly undesirable, and every attempt should be made to correct this situation, it actually has the side benefit of reducing the local rail-to-earth voltage, which can otherwise be quite substantial.

Apparently, there are only a few situations in Sydney's electric traction system where a bonded system is also permanently earthed, because doing this can lead to continuous dc electrolysis corrosion problems, unless it's carefully managed.

See *Section 6.4.7*, *Line-Side Fencing* for an idea of some of the problems associated with electrolysis corrosion, and in particular *Figure 712*.

THE ROLE OF THE SPARK GAP

A spark gap protecting an OHW structure provides a means of minimising risk.

The spark gap is normally an *open circuit*, but it will *short circuit* if the voltage across it exceeds about 600 to 800V (see "Acceptance Criteria" note in *Figure 472*).

"Open Circuit" State

This normal state prevents rail volts from continually being applied to the OHW structure being protected.

If the structure was directly connected to rail, then rail volts may leak from the connected structure into earth. This leakage can occur by way of the steel reinforced concrete footing

that the structure is mounted on, or if the mast is direct buried in concrete in the ground (a PP mast). It may also find other paths back to the substation negative and corrode services along the way. So, a spark gap in its "open" state helps to prevent this from happening at this location.

"Short Circuit" State

The small gap inside the spark gap flashes over and *shorts out* when more than about 600V is applied to it, e.g. if the 1500V insulation supporting the OHW fails to insulate on the structure. The structure is then electrically tied to the traction rail until the spark gap is renewed.

The purpose of the short circuit state is to force a high level fault current to flow so as to help trip the associated dc circuit breaker/s back at the substation and/or sectioning hut, thus removing the +1500V from the affected OHW. The spark gap's roughly 600V flashover is set to a fairly value in order to avoid *nuisance operation*, i.e. voltage transients that aren't really faults shouldn't short out the spark gap, to avoid possible long term electrolysis problems.

In this scenario, if the S/S or S/H circuit breaker trips, then a supervisory indication of this event is sent to the Electrical Operating Centre and action should then be taken immediately to remedy the situation.

Testing

Being a high impedance device, sometimes a spark gap shorts out without a true fault being present (e.g. due to nearby lighting surges), and it remains in this state until it is tested at some later time, which could be months away.

Unfortunately, spark gaps don't show any obvious sign that they have shorted out, so they require frequent periodic *testing* to detect and renew short circuited module units. The corrective action is to replace the spark gap module unit with a new one – a relatively simple thing to do. I understand they can also be refurbished a few times by machining on a lathe (?) to remove the minor arcing "splash" marks to reinstate the tiny isolation gap.

Until the blown spark gap is discovered and replaced, it is possible that low levels of leakage current can find their way back to substation negative via nearby pipelines and other services or structures. If this happens for months, this may lead to long term nasty corrosion effects on nearby services. Some metallic services (such as pipe lines) have regular insulated breaks along their path, to minimise the chance of leakage currents taking this path and of electrolysis causing a problem.

According the original Technical Maintenance Plan, each spark gap required:

- A visual examination every 6 weeks with latitude of 1 week (refer to Service Schedule E12002), and
- An electrical test (for confirming electrical isolation) every 3 months with latitude of 2 weeks (refer to Service Schedule E12003).

THE SIMPLE SPARK GAP

The spark gap is usually a vital piece of equipment in any bonding circuit.

The standard spark gap arrangement – fitting 10/4 – has been around since at least 1955, and has served Sydney's electrified rail system well over this time. Refer to spark gap shown in *Figure 466*, which is connected to a steel angle (with bond wire U-bolt connection), mounted on 2 red low voltage insulators and installed on a concrete wall.

Figure 466 - Typical Spark Gap mounted on wall

Its main working component is a brass *spark gap module* containing a perforated "melinex" separator disc (an insulator), sandwiched between 2 brass surfaces. When the stress across these surfaces exceeds about 600V, it causes a flashover between the brass surfaces through one or more holes in the melinex washer (which used to be mica I understand). The flashover causes the module to permanently short circuit and this will permit heavy (fault) current to flow.

Refer to *Figure 467* for a view of the main internal parts of the spark gap module. The left photo shows a disassembled spark gap with a typical wrench used for assembly. The top right photo shows the special perforated melinex washer, and the bottom photo shows the assembled unit. A black rubber seal installed on the pad is meant to keep water out of the module. The standard arrangement drawing is shown in *Figure 471*.

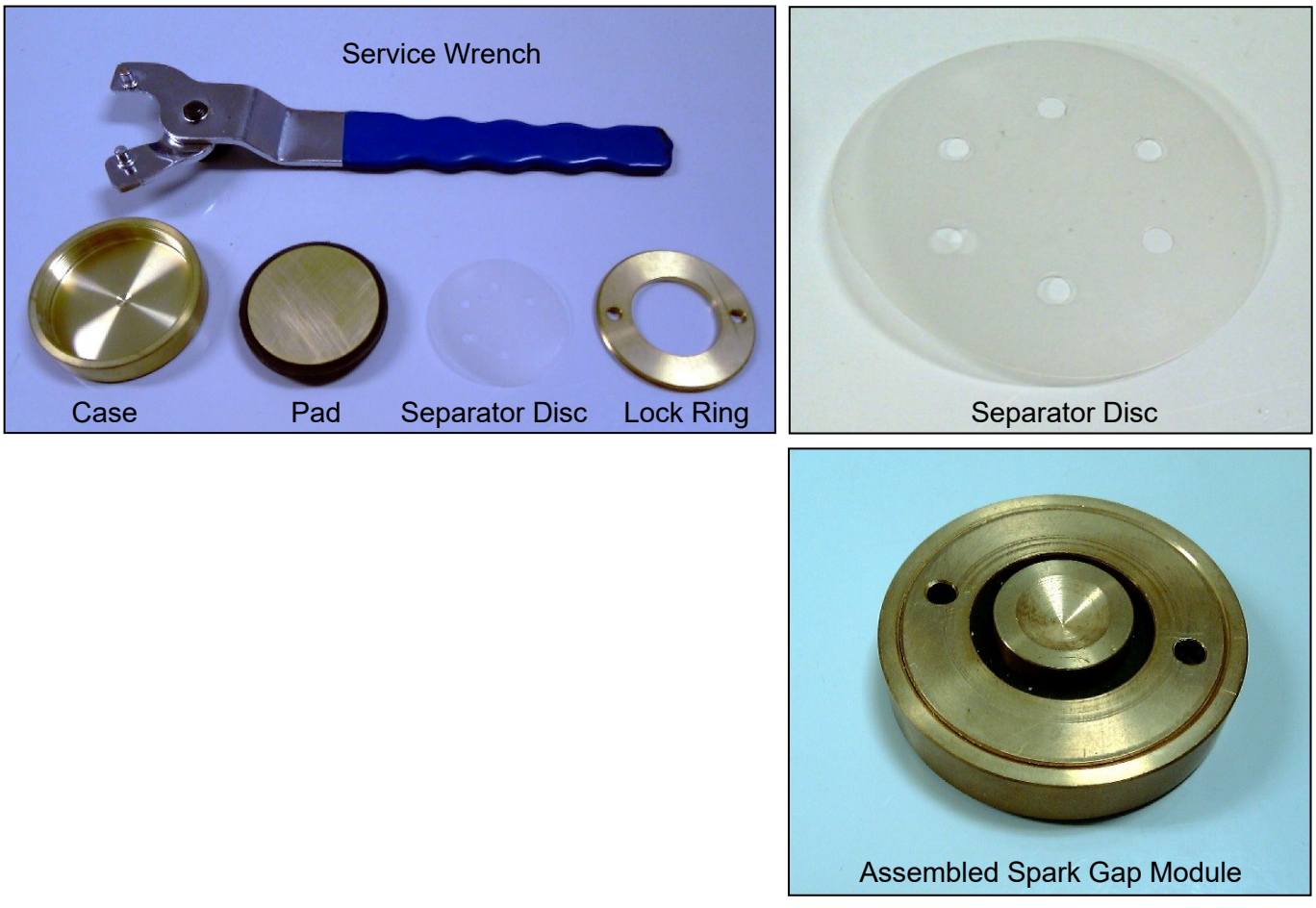


Figure 467 - Spark Gap Capsule & its internal components

The 600V voltage threshold is set relatively high in an attempt to reduce "nuisance" trips, which would otherwise put unnecessarily prolonged *rail volts* on the structure being protected (which is, of course, counterproductive). It is mostly meant to deal with genuine 1500V faults.

This type of spark gap does not reset itself. Each of them throughout the electrified network need to be periodically inspected and tested, and its module replaced if found shorted out.

It is important that any short circuited spark gap modules be replaced as soon as practical, because in the meantime rail volts are continually applied to the structure being protected. This may cause corrosion of nearby services in time. Refer to *Figure 468* to see the inside of a failed spark gap, which shows arcing damage (causing the short circuit). The higher the current, the more significant the arcing mark.

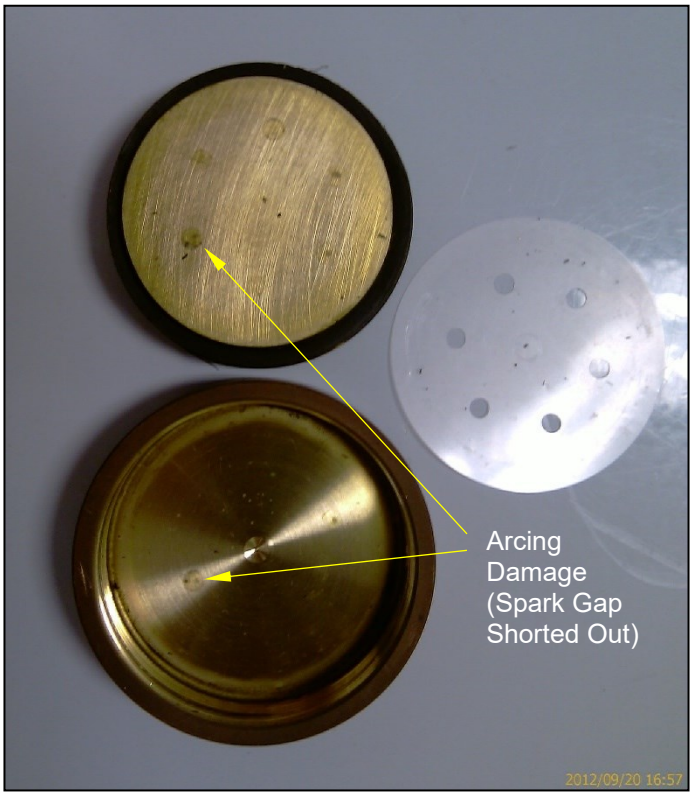


Figure 468 - Innards of failed Spark Gap

The spark gap module is mounted in a sideways U-shaped spark gap bracket as shown in *Figure 471*. The bracket is installed onto the structure being protected by the spark gap, using its M20 stud, spring washer & nut. The capsule is mounted with the M12 set screw and central terminal facing down (to reduce the likelihood of water ingress past the rubber seal into the melinex washer).

The brass body is insulated from the bracket with a flat Bakelite (insulating) pad above it, and sandwiched between these is the lug which carries the 95mm² cable that connects to the track.

The spark gap module is kept in place by tightening the M12 set screw to achieve an appropriate clamping force, which is then locked in place by the accompanying lock nut. This set screw should not be over-tightened, or it will deform the U-shape in the steel mounting bracket – see *Figure 469* for an example of over-tightening.

This configuration has proven to be a fairly robust arrangement in the harsh rail environment.

A spark gap is normally installed on an OHW mast, and is positioned about 500mm or so above ground level, providing easy access for periodic testing. There may be a case for installing it in a more inaccessible place away from reach of the general public, but it should still be readily reached for frequent testing & maintenance.

If a spark gap is installed on a concrete wall, as shown in *Figure 466*, and there's a chance of the metal bracket touching steel reinforcing within the concrete, the bracket would need to be mounted to the wall with some form of insulation. *Figure 466* shows the use of a pair of low voltage insulators (in red). Alternatively, this isolation could be achieved by means of an insulation pad & ferrules (which can be tested for electrical isolation).

Figure 469 shows a badly installed Spark Gap arrangement. The 2 main objections here (apart from the deformed "U" bracket mentioned above) are the direct connection to a concrete wall (with no insulation), and the woefully inadequate bonding wire lug connection at the top of the steel bracket, with only ~5mm bolted connection. (Contrast this with the proper 10mm stainless steel U-bolt connection shown in *Figure 466*. In fact the situation in *Figure 469* had to be corrected and is now similar to that shown in *Figure 466*.)

Figure 469 - Badly installed Spark Gap arrangement

Figure 470 shows a spark gap module improperly installed. The brass module is resting against the internal "U" shape in the bracket, meaning the lug is shorted out to the spark gap bracket (rendering the bakelite insulation between lug and bracket useless). This will, in turn, place rail volts onto whatever structure is being protected by the spark gap – a really bad outcome.

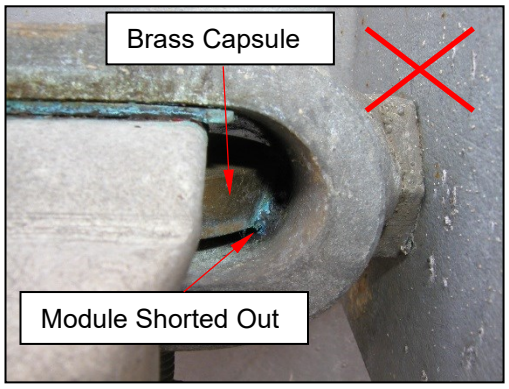


Figure 470 - Badly installed Spark Gap being shorted out

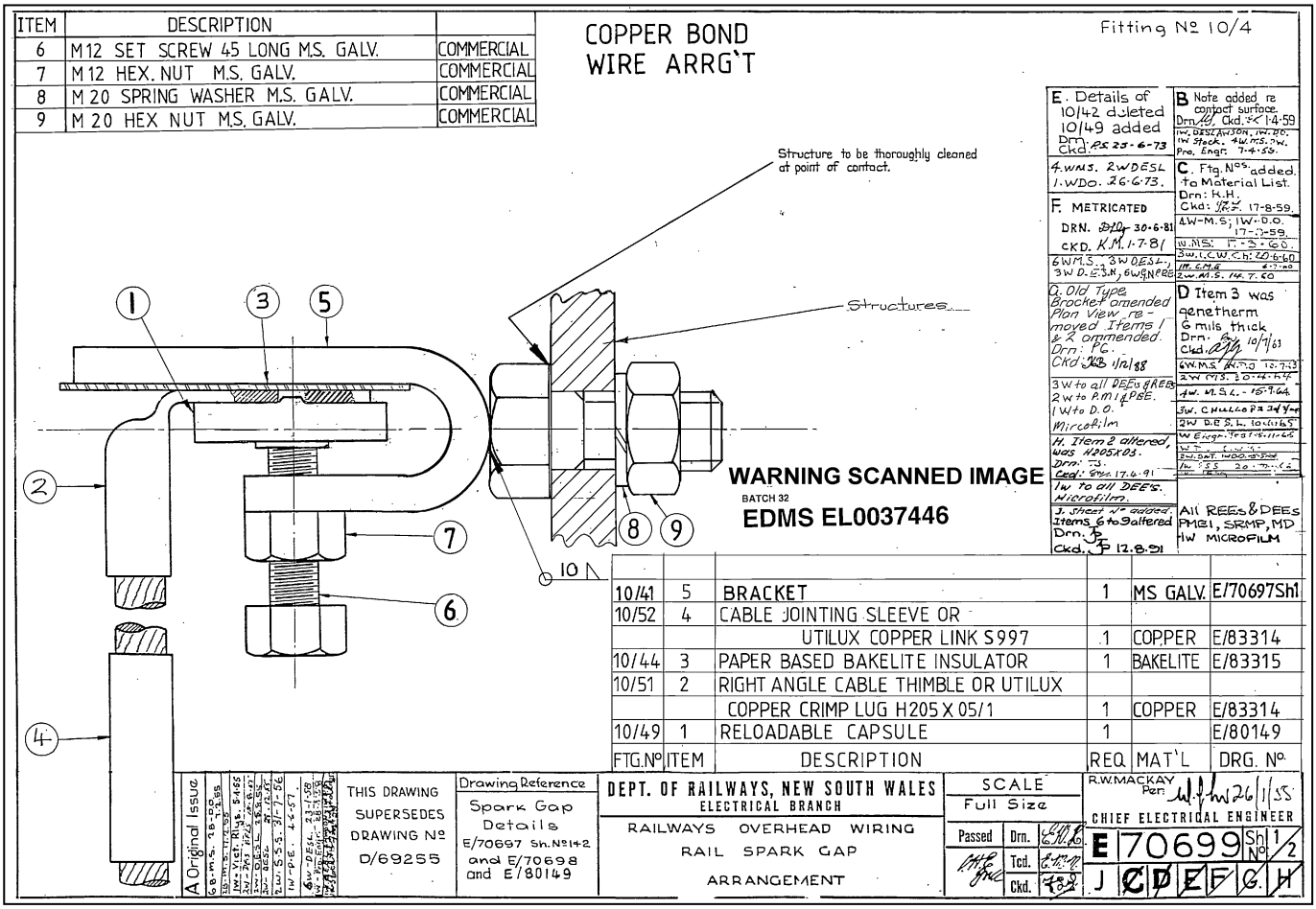

ITEM DESCRIPTION
6 M12 SET SCREW 45 LONG M.S. GALV. COMMERCIAL
7 M12 HEX. NUT M.S. GALV. COMMERCIAL
8 M20 SPRING WASHER M.S. GALV. COMMERCIAL
9 M20 HEX NUT M.S. GALV. COMMERCIAL
COPPER BOND WIRE ARRG'T
Fitting Nº 10/4
Structure to be thoroughly cleaned at point of contact.
Structures
WARNING SCANNED IMAGE
BATCH 32
EDMS EL0037446
10/41 5 BRACKET 1 MS GALV. E/70697Sh1
10/52 4 CABLE JOINTING SLEEVE OR UTILUX COPPER LINK S997 1 COPPER E/83314
10/44 3 PAPER BASED BAKELITE INSULATOR 1 BAKELITE E/83315
10/51 2 RIGHT ANGLE CABLE THIMBLE OR UTILUX COPPER CRIMP LUG H205 X 05/1 1 COPPER E/83314
10/49 1 RELOADABLE CAPSULE 1 E/80149
FTG.Nº ITEM DESCRIPTION REQ. MAT'L DRG. Nº
A Original Issue
THIS DRAWING SUPERSEDES DRAWING Nº D/69255
Drawing Reference Spark Gap Details E/70697 Sh.Nº1+2 and E/70698 and E/80149
DEPT. OF RAILWAYS, NEW SOUTH WALES ELECTRICAL BRANCH
RAILWAYS OVERHEAD WIRING RAIL SPARK GAP ARRANGEMENT
SCALE Full Size
R.W.MACKAY CHIEF ELECTRICAL ENGINEER
E 70699 Sh Nº 1/2

Figure 471 - Drawing of standard Spark Gap arrangement

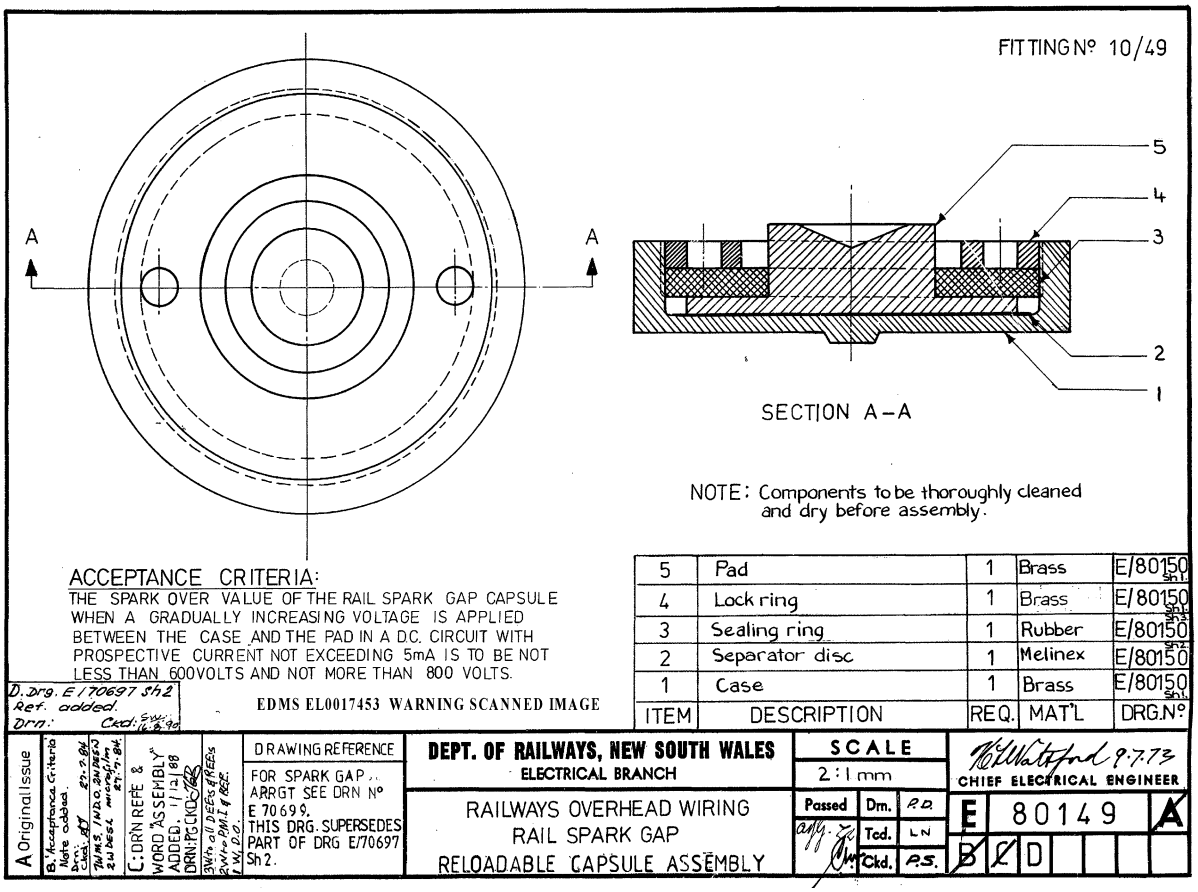

FITTING Nº 10/49
A
A
5
4
3
2
1
SECTION A–A
NOTE: Components to be thoroughly cleaned and dry before assembly.
ACCEPTANCE CRITERIA:
THE SPARK OVER VALUE OF THE RAIL SPARK GAP CAPSULE WHEN A GRADUALLY INCREASING VOLTAGE IS APPLIED BETWEEN THE CASE AND THE PAD IN A D.C. CIRCUIT WITH PROSPECTIVE CURRENT NOT EXCEEDING 5mA IS TO BE NOT LESS THAN 600VOLTS AND NOT MORE THAN 800 VOLTS.
EDMS EL0017453 WARNING SCANNED IMAGE
5 Pad 1 Brass E/80150 Sh1
4 Lock ring 1 Brass E/80150 Sh1
3 Sealing ring 1 Rubber E/80150 Sh2
2 Separator disc 1 Melinex E/80150 Sh2
1 Case 1 Brass E/80150 Sh1
ITEM DESCRIPTION REQ. MAT'L DRG.Nº
DEPT. OF RAILWAYS, NEW SOUTH WALES
ELECTRICAL BRANCH
SCALE 2:1 mm
RAILWAYS OVERHEAD WIRING
RAIL SPARK GAP
RELOADABLE CAPSULE ASSEMBLY
CHIEF ELECTRICAL ENGINEER
E 80149 A

Figure 472 - Drawing of Spark Gap Module assembly

TYPES OF SPARK GAPS

There are a few types of spark gaps used in Sydney's system, the simplest and most popular being the standard railway unit (fitting 10/4 described above) which includes a thin perforated plastic washer sandwiched between brass plates (where the flashover occurs).

Others devices may or may not include an actual "spark gap", but instead rely on modern electronics to achieve the desired outcome. The sparkless operation may be an advantage in combustible environments, e.g. coal loaders (in the days when Sydney had electric locomotives).

Some devices can give a signal to the supervisory control to indicate that the device has tripped. Examples include the "Soule" and the "Ferraz" units, but there may now be other railway-approved propriety items being used. At some crucial locations it may be desirable to keep the device in the "open" state for as long as possible and to be notified immediately when this is not so.

In areas where lightning voltages can cause problems with standard spark gaps shorting out prematurely, other devices have been trialled. For example, in the Blue Mountains I understand the "Dehn" spark gap is now accepted for use, to provide better immunity to these lightning voltage transients and help combat the nuisance trips (yes, I mean it in both senses).

BONDING WIRE OR CABLE

There are generally 2 approaches to bonding any situation (and sometimes there's a mix of these):

- *Bonding Wire* – where the wire is tensioned to span large distances (and in doing so, connecting to structures to be bonded in the circuit), and

- *Bonding Cable* – where the wire is under no tension and is simply cleated to a wall or other structure on its path to pick up the various steel items that need bonding.

Bonding wire (bare) is used to aerially connect consecutive OHW structures to a common spark gap. For example, this approach was used at Wolli Ck Station in the Airport Line (the design is shown on drawings EL0284206 to 208). Here, a bare wire under tension electrically connects all the portal structures through the station together (with each connection made about half way along each portal bridge). It also connects various horizontal safety screens. Bonding cable then connects one end of this aerial circuit to a spark gap and then to rail.

So, if the conductor can be located out of reach of the public, then it is probably cheaper to simply install bare wire (although it probably needs to be tensioned to keep it in the air without too much sag or blowout, whilst spanning distances of up to 60m or so).

37/1.75mm (90mm²) hard-drawn bare copper has been used in this situation in the past. Refer to drawing EL0002963 for instance. Also see *Figure 482* further on.

Bonding cable is used far more often in bonding circuits. This is mainly because the wire needs to follow a path which can be somewhat contorted when interconnecting the various steel items to be bonded.

The 95mm² (or 120mm²) copper bonding cable normally uses multi-stranded copper wire for flexibility as it sometimes needs to take sharp right-angle bends and stay set in shape.

This cable needs to be held in place along its route, and usually employs strong steel cleats with maximum spacing of up to 1,000mm. This is important since there are huge electro-mechanical forces involved if and when there's significant dc fault current on the structure being bonded. This fault should cause enough current to trip the associated dc circuit breakers to isolate the fault. (Bear in mind that the local dc fault level can be in the tens of thousands of amps, in some places more than 50kA as I recall.)

The restraint of the cable along its route is necessary because it may be possible for an unsecured (unrestrained) cable to whip about wildly under fault conditions and injure someone. So, the solid clamping of this cable at regular (up to 1,000mm) intervals acts to prevent the cable from such dramatic wanderings under the huge fault current surge before the breaker trips supply.

The thick insulation surrounding the cable can normally allow it to be located near the general public.

This insulation can also help prevent the bonding conductor shorting out to nearby services which may be earthed (e.g. metal air conditioning ducting). The bonding circuit and any local earthing circuits must not interconnect for obvious important reasons.

Refer to drawing EL0007855 for an example – shown in *Figure 473*. This drawing shows bonding at a "Jack Arch" bridge, but uses a hard drawn copper wire with black pvc covering to allow the wire to be tensioned (to 2kN) so that it can span larger distances without the need for more regular intermediate attachments to the bridge.

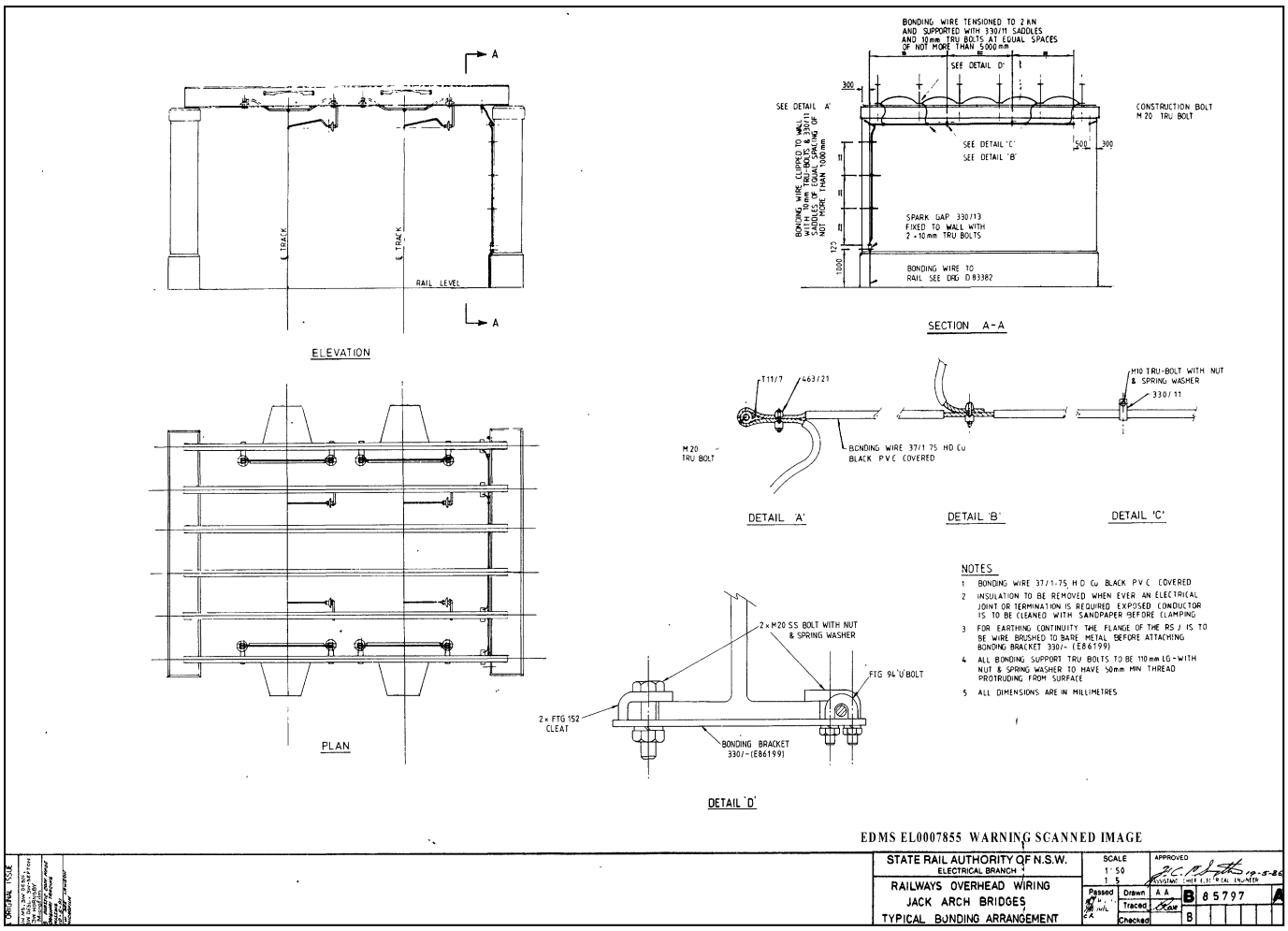


Figure 473 - Typical tensioned Bonding arrangement for Jack Arch Bridges

HORIZONTAL SAFETY SCREENS ON BRIDGES

Horizontal safety screens are sometimes installed on overline bridges at a position directly above the live OHW conductors and equipment. This is likely to act as a type of barrier if someone were to dangle an object directly down towards the OHW. These screens generally need to be bonded, but should ideally not be connected to any other steelwork such as the bridge fence (to isolate the area). For example, refer to the bonding drawing on Jack Arch bridge in *Figure 473*.

In the "good old days", it seemed to be that about once every few months someone somewhere would try to self-harm, by climbing over the bridge fence and standing or sitting on a horizontal safety screen (or "smoke screen" as they are sometimes wrongly referred to). In some cases, they may have been oblivious to the potential danger they were facing.

One could tell this was happening by referring to the regular "Elec Trouble" reports of daily switching and irregularities. When identified, Elec Trouble would be contacted to turn OHW power off so that the situation could be rendered safer (although the person could still fall from this height of 5.5m or so above track!). Quite likely, police would be involved to persuade the offender to climb back over to safety. And in the meantime, again quite likely, trains would be stopped (including all power, lighting and air conditioning on board the affected trains) until the situation was resolved. If this happened prior to or during the peak hours, even a short delay could put train operations into absolute chaos for hours.

It seems that over the recent years, a concerted effort was made to implement ways to prevent people from accessing hazardous situations, including the above scenario. Notably there are

many more vertical steel mesh screens located on bridges, that prevent people from doing stupid things. An example of such a screen can be seen further back in *Figure 259*.

These days it is rare to hear of any instances of people gaining access to horizontal safety screens, which is a magnificent outcome.

These screens are normally designed and installed by the Civil section.

Refer to Standard EP-08000007-SP, "Safety Screens for Bridges Over 1500V Equipment".

RAIL CONNECTION

A bonding cable connects the spark gap to the traction rail of the track, or to a signal's impedance bond. This vital connection is made by signalling staff. Apparently this is because a connection to the wrong rail or the wrong track, or an incompatible method (depending on the type of signalling system installed), can adversely impact the signals.

An electrical connection to the rail of a track takes the form of a lug-connected bonding cable fastened to a thread installed in the web of the rail.

This thread can be made by "Cadwelding" it to the web using an exothermic reaction as shown in *Figure 474*. ("Cadweld" is a commercial name for this specialised welding process.)

Alternatively, in the past a stainless steel tapered bolt arrangement could be inserted into a hole drilled into the web. Tightening the nut expands the tapered bolt in the hole to provide a solid electrical connection to the rail. But it needs to be tight!

Figure 474 - Threaded stud "Cadwelded" to rail web

OTHER RISKS

When it comes to unusual situations, such as large air space developments above the OHW, the risk of 1500V dc livening up, or it leaking into the steel that's supporting OHW equipment (due to failed primary insulation), needs to be assessed each time. It seems that no two situations are identical – there are usually many variables involved.

As such, it's important that a proper risk assessment be carried out in each case, to flush out the potential issues and deal with the risks. You cannot just simply assume everything's the same and copy the bonding solution used elsewhere without proper thought. And things like the standards, that govern bonding approaches, can also alter over time, so any such changes need to be incorporated into the adopted "bonding" solution.

The final bonding design would need to be signed-off by Earthing & Bonding experts.

ISOLATION FROM OTHER SERVICES

It is extremely important that any surrounding equipment or services not associated with the OHW, be kept totally isolated from the OHW bonding scheme, as far as this is practicable. Doing this greatly simplifies the situation and should also reduce the possible risks (including transferred risks).

One example is to keep any architectural ceilings or roofs at stations physically and electrically away from any bonded OHW drop verticals that may be located nearby. In the past, insulating "shrouds" (made from fibreglass or the like) have been formed and installed to surround a drop vertical, so as to prevent such contact with nearby non-bonded equipment.

LEVELS OF INSULATION

Most of Sydney's OHW system uses only one level of insulation – the *Primary Insulation* for 1500V. However, there are certain circumstances that can benefit from additional levels of insulation – sometimes referred to as "Supplementary Insulation", including *Secondary Insulation* and a further level of *Tertiary Insulation*. These various levels of insulation for the 1500V dc system are listed below.

Primary Insulation

This is the main 1500V insulation for allowing the OHW to be energized and reliably operated.

The insulation level is somewhat higher than it needs to be for a 1500V system, but this higher level was implemented to minimise any adverse outcomes (particularly train stoppages) during severe weather events such as heavy rain and lightning.

Even so, there are 3 levels of *1500V Primary Insulation*:

- For ***Anchors*** (the highest level), then
- For ***Support***, and then
- For ***Registration*** (the lowest level of insulation).

These are discussed in *Section 5.1.7.2, Insulation Coordination*.

Secondary Insulation

Secondary insulation provides an independent level of insulation in addition to the all-important 1500V primary insulation of the live OHW.

This secondary insulation is normally a low-level insulation for maybe up to a few hundred volts – it does not need to be for 1500V, as that function goes to the primary insulation. It is mainly intended for preventing dc leakage currents to earth.

Refer to standard arrangement drawing shown in *Figure 475*, which depicts the arrangement, the fittings and the requirements (in the notes) needed to include secondary insulation on a standard Mark-2 cantilever on a drop vertical. *Figure 477* shows an example of the use of secondary insulation in a bonding circuit.

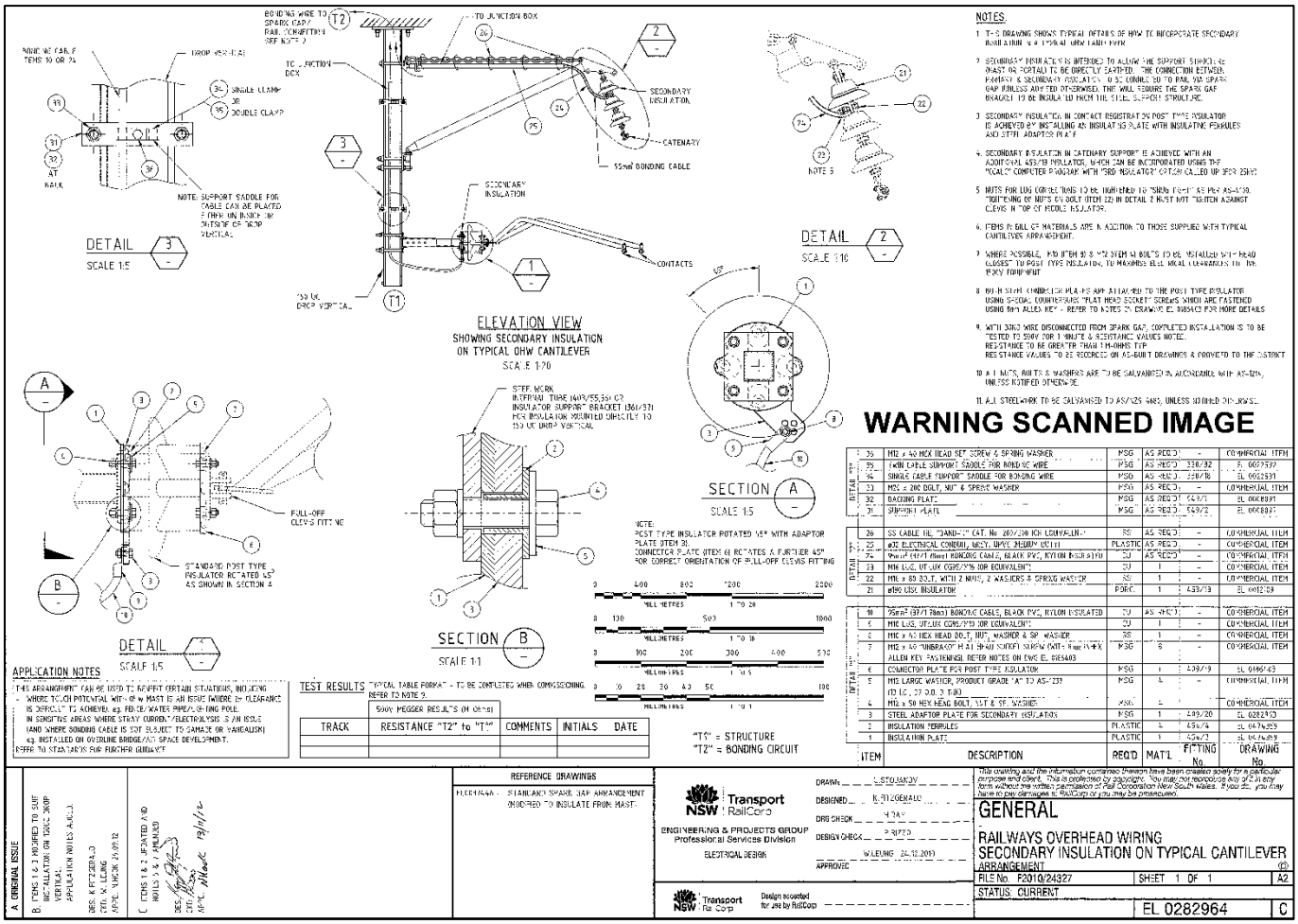


Figure 475 - Application of Secondary Insulation on typical OHW Cantilever

Figure 476 is an exploded view of the secondary insulation employed in a pull-off arrangement per *Detail 1* in *Figure 475*.

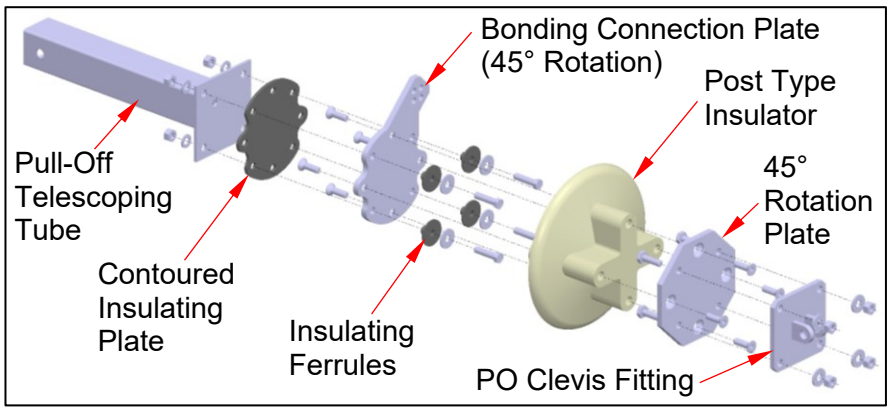


Figure 476 - Exploded view of Secondary Insulation in Pull-Off

This configuration creates a tap-off point – the "Bonding Connection Plate" (fitting 409/20) – for connecting a bond wire using the standard SS U-bolt or a cable lug. This connection is isolated from the 1500V (via. primary insulator) and from the rest of the steel cantilever (via. secondary insulation). The "Contoured Insulating Plate " and 4 "Insulating Ferrules", all made from a black acetal copolymer (such as Sustarin-C), provide the robust secondary insulation to isolate this intermediate plate.

Because the resin post type insulator uses insert sockets instead of simple holes for connecting to adjacent parts, this required 2 plates – one plate that rotates the insulator 45° and then another plate to rotate a further 45°, bringing alignment back to normal to allow connection to the Telescoping Tube (or other standard hardware). This approach gives the space needed to install the insulating ferrules and connecting fasteners.

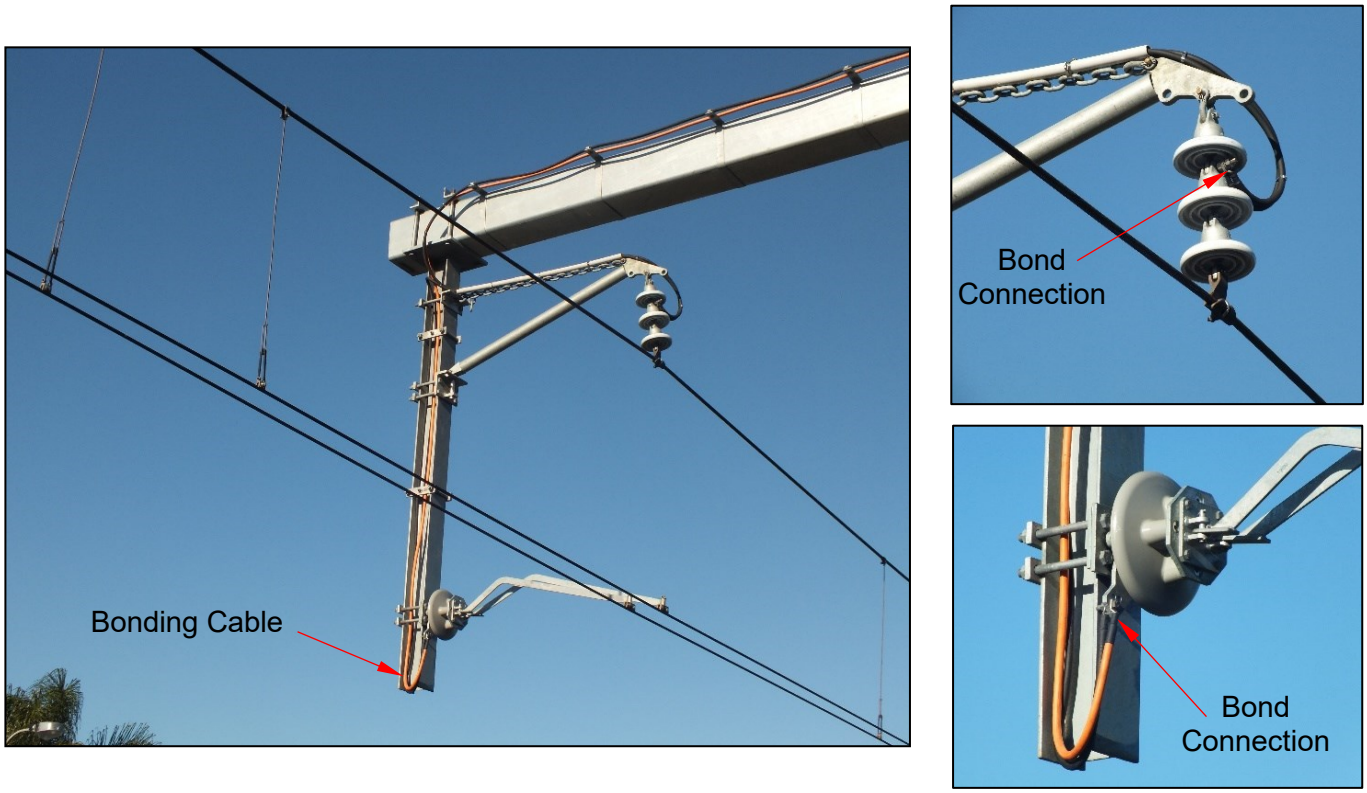


Figure 477 - Recent example of bonded Secondary Insulation (Glenfield Station)

Tertiary Insulation

This provides yet another (third) independent level of insulation on top of the primary and secondary insulation.

Like secondary insulation, tertiary insulation can be a low-level insulation of up to a few hundred volts.

The aim of this further layer of insulation is to reduce the probability of even very small levels of leakage current from occurring. This may be needed in areas that might be sensitive to minute leakage currents.

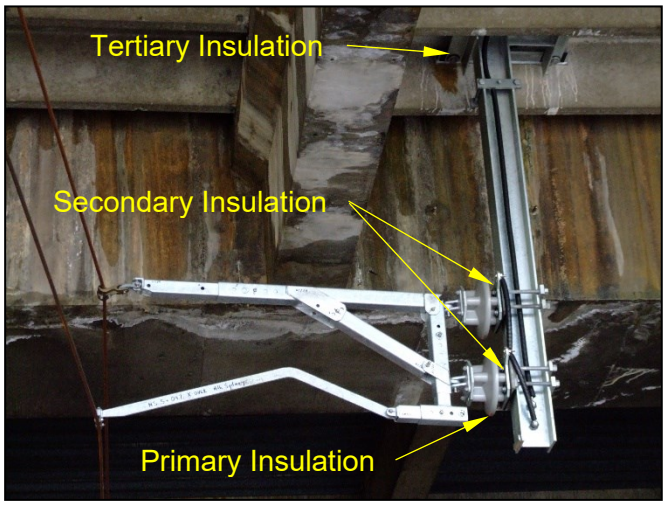


Figure 478 - Tertiary Insulation scheme at North Sydney

Figure 478 is an example of the inclusion of tertiary insulation. (This situation is described further below.) Note that surge protection on 1500V cables, installed as part of the nearby switch bank, should help reduce the chance of any surge problems here.

To Bond or Not to Bond?

While it is generally considered that bonding of all sorts of crucial infrastructure is desirable in minimising certain risks, unfortunately the bonding itself can introduce other risks.

Figure 479 shows a number of possible bonding scenarios. Some are practical while others are undesirable or impractical for various reasons.

The bonding design in unusual circumstances (e.g. under an air-space development) requires a good understanding of the pros and cons of each bonding scenario.

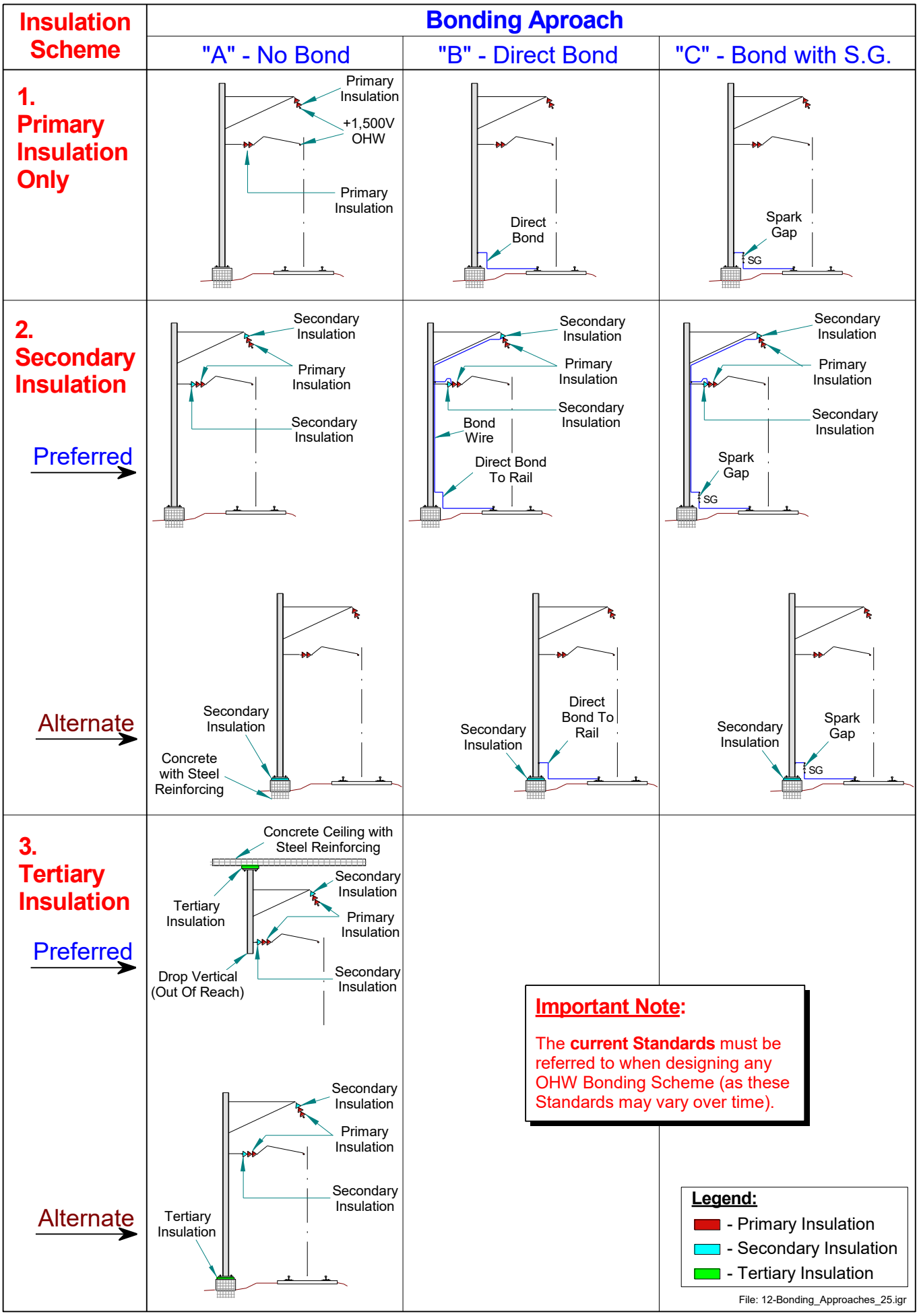


Figure 479 - Various Bonding Insulation schemes

To Bond

As described previously, bonding a piece of crucial steelwork such as a mast located near or on the station platform, or the unenergized side of the support & registration fittings installed under an overline bridge, is intended to trip the electrical protection in the unlikely event that the thing livens up. For instance, this could be due to one of the several primary OHW insulators installed on the structure failing to insulate.

This situation traditionally requires that the steelwork be connected by a heavy-gauge cable (90mm² copper or similar), with the other end of the cable connected to traction return rail, and a spark gap installed in series at some convenient position along the way. If a fault occurs, the open spark gap short circuits ("blows"), thus electrically connecting the livened steelwork to rail, which should cause enough heavy current to flow so as to trip the dc circuit breaker/s and isolate the 1500V supply.

Preventing the structure from livening up is intended to:

a) Protect people from being given an electric shock, and also to
b) Prevent large stray leakage currents (heading back to substation) from flowing through nearby pipework and surrounding support infrastructure, and corroding or otherwise damaging these things.

But if the spark gap blows, it remains short circuited until the spark gap module is replaced (which can be weeks away). Unfortunately, during this time the steelwork is connected directly to traction rail. This means that the potential of the structure is tied to the local rail volts (which is then a function of the current drawn by trains and the rail resistances from nearby substations). During this time the rail/structure voltage can find its way back to substation and corrode things on its way – the very thing that it is intended to prevent. Thankfully the currents would be relatively small, but they can remain there for weeks until the spark gap is renewed, and still cause insidious corrosion damage.

To Not Bond

Installing additional insulation to the primary 1500V insulation can be a way of significantly reducing the risks associated with insulation failure.

As described above, *Secondary Insulation* is a second level of insulation in addition to primary insulation. In some circumstances it could be argued that having this added insulation obviates the need for any bonding circuit, which itself has its own risks anyway (described above).

Refer to *Figure 480,* where a second *K-Line* insulator is installed in series with the main *K-Line* primary insulator, for both the catenary and contact wires heading to an anchor at Chatswood. There's no bonding here, relying instead on the huge double-insulation level.

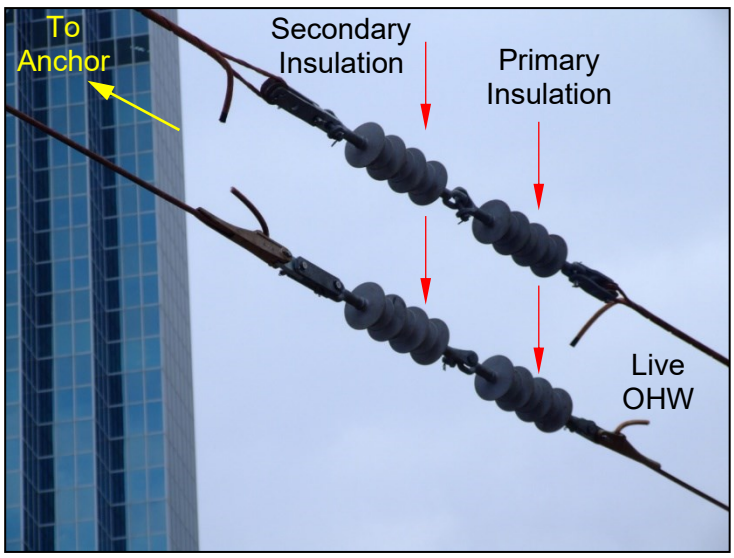


Figure 480 - 2 primary insulators in series to help obviate the need for Bonding to track

One benefit of secondary insulation is that it can also allow a bonding wire to be connected to the junction between the primary and secondary insulation, then connected to rail. In this way, the anchor or support structure can be deliberately earthed, making it somewhat immune

to the dc system. In this case, there may be no need for a spark gap (with its routine testing costs) in the bonding circuit. Indeed, the spark gap may become overly sensitive to spurious voltages in this situation of connecting to a floating potential, albeit with a very small exposure. This approach is shown roughly in *Figure 479*, *Insulation Scheme 2 "Preferred", Cases B* or *C*.

Refer back to *Figure 477* at Glenfield Station. Here the catenary primary insulation has 2 disc insulators, so a 3rd insulator was added in series to act as secondary insulation – this is an easy thing to do (and the CCalc program can include this 3rd insulator in its calculations if needed). Likewise, (and as described above), the contact primary insulation is a single post type insulator which is bolted to a steel bonding plate, then a specially shaped "Sustarin-C" plastic plate is installed behind it with insulated ferrules (for 4 attachment bolts) forming the secondary insulation, which is then bolted to the drop vertical with 4 more bolts. A bond wire is connected between primary and secondary insulation on both the catenary and contact arrangements, and this goes to a common bonding circuit for the station area, with (or without?) a spark gap to traction rail.

Care needs to be exercised with this secondary insulation, as it can render the metalwork that's located between the primary and secondary insulation at a floating potential, unless it's connected to something – see above for instance. It would be prudent to locate any metalwork with such floating potential well out of the way of people.

Tertiary Insulation provides a 3rd level of insulation. *Figure 478* shows a Mark-2 Tunnel Cantilever, with tertiary insulation installed as a means to further ensure the dc cannot flow into the above concrete beams to corrode them. The black wiring on the DV goes to 2 "test points" near the bottom of the DV, to allow periodic testing of the secondary and tertiary insulation. Surge arresters are connected to the OHW (thanks to a nearby 1500V switch bank for all tracks), which greatly reduces any chance of lightning flashover here.

Because of the additional level of insulation, it's a "belts and braces" solution that may find application in certain crucial situations.

As previously noted, an alternative of installing a long run of bonding wire to bond to this DV steelwork, would have its own risks. An example might be electrolysis corrosion, if a cable cleat, for instance, penetrated the bonding cable insulation and electrically connecting to the bonding wire. In this case, it might transfer rail volts (due to a blown spark gap) to the cleat bolt which might be touching one of the many steel reinforcing rods embedded in concrete. Or, the bond wire may unintentionally connect to other services (such as steel air-conditioning ducts) at earth potential.

These schemes that provide additional insulation rely on the integrity of the added insulation, and this should be periodically checked by testing.

Again, as with secondary insulation, care should be exercised with any metalwork that's at a floating potential, to keep it away from people. This is probably not an issue in *Figure 478*.

Example: Safety Screens on Overline Bridge

The overline bridge shown in *Figure 481* has 3 horizontal safety screens (one located above each of the tracks) on the pedestrian-side of the traffic/pedestrian bridge.

The normal long-standing practice of insulating each of the safety screens from the bridge steelwork, using *insulating ferrules*, and bonding *only* the screens (not the bridge) to a spark gap, seems to have been dismissed in this situation.

Instead, all horizontal safety screens here seem to be directly connected to the steelwork of the bridge. And the bridge itself has a spark gap installed on the bridge steelwork (seen near bottom-left of the picture) which is then connected to rail.

To my way of thinking, this is not a good outcome, unless there's a serious risk of the 1500V OHW somehow connecting with the steelwork of the bridge, e.g. through a damaged pantograph(?).

The big problem with this approach is the loss of *containment* of the bonding circuit. If and when the spark gap shorts out, the entire bridge is brought to the potential of the local rail volts, which can be quite large. This can lead to stray currents anywhere the bridge's steelwork ultimately connects it to the earth, and this may accelerate corrosion. And this includes any connected fencing, as discussed further on in *Section 6.4.7* (the same bridge), with relatively rapid corrosion seen in the accompanying pictures in *Figure 712*.

Given that there are substantial vertical screens now installed on the bridge, it may be prudent to remove the bonding circuit entirely, i.e. "to not bond". This would eliminate its risk, along with the associated ongoing maintenance costs. The risk of a pantograph somehow livening the bridge would need to be considered, but the chances of this happening are quite remote, and this risk occurs at numerous other bridges throughout the electrified network anyway (with very few problems, if any, ever reported). The presence of effective vertical screens can totally change the "bonding" situation in a very beneficial way.

Figure 481 - Bonding to Overline Bridge Steelwork (?)

ISOLATION BARRIERS

A good alternative to bonding is to provide some means of isolating people away from the hazard, e.g. using appropriately sized and positioned barriers. Standard EP-08160002-SP, "Safety Barriers for OHW Structures" provides requirements for the installation of safety barriers to help control the risks in various situations.

Installing a barrier of suitable dimensions, between the live OHW and nearby infrastructure (such as an overline bridge with pedestrian access), can vastly reduce the risk of someone somehow "touching" or coming anywhere near the live equipment.

There are some situations where bonding is installed but it's presence is undesirable for some reason. For example, a mast on a platform located next to an earthed metal vending machine, resulting in a possible "touch potential" hazard. To help make the situation "safe", it is possible to install safety barriers (such as insulating panels or a shroud) surrounding the structure to a suitable height, so that no one can touch the metal structure whilst also touching the vending machine with the other hand.

A rather extreme example of a decent barrier is provided in tunnels, where the tunnel lining itself would normally provide a natural barrier to the outside world, and makes it extremely unlikely that someone will touch the steel support brackets or live OHW conductors.

Over the past decade or two, this "barrier" approach has been gaining popularity throughout Sydney's system (especially at overline bridges, by utilizing tall curved "bat wings" or the like as barriers – refer to *Figure 259* for instance). There can be several big benefits to be had from doing this one-off action.

See also *Section 5.1.26* for more information on these risks.

USING A COMMON BONDING CIRCUIT

Concept

Sometimes a collection of adjacent OHW structures can be bonded together to form one bonding circuit, to employ one spark gap for the group. This can happen for structures on a viaduct, or bridge or at some railway stations for instance, and possibly using aerial bond wire to connect them. See *Figure 482* for instance.

A significant benefit of this approach is that the single spark gap can be installed at a convenient location that can allow its regular testing (to confirm its integrity).

This approach can save money too, both in the initial outlay and, probably more importantly, in the ongoing maintenance cost of testing the spark gap (with only one instead of many spark gaps to test).

However, there may be a down side to this approach – see next heading.

Figure 482 - Example of Aerial Bond Wire connecting OHW Structures on bridge (Dapto to Kiama)

Maintainability

The down side to the *common bonding circuit* approach (above) can be that, if a fault in the bonding circuit happens, it can be difficult and time consuming to trace back to the exact cause, since the bonding cable ties all structures electrically together.

So, attempts have been made in bonding designs over recent years, to not only improve the convenience in the way bonding circuits are tested, but also to include ways to quickly find a fault, should one occur.

This may involve setting up several isolation points in the bonding circuit to help hone in on the culprit. An example is the use of isolating links installed on small insulators at accessible (although restricted) locations.

Bonding Cable Redundancy

A distributed bonding system can be useful at places like stations, where many structures need to be bonded. This way, a single spark gap to rail can be used for the group of structures.

In such a distributed bonding arrangement, where possible, it's a good idea to arrange the cable to have some redundancy, so that if the cable is damaged and becomes open circuit at one point, bonding is still provided by an alternate path. A closed circuit, or figure-of-eight arrangement, can help in this regard. And it can also help lower the circuit resistance.

A good example is Parramatta Station, where an array of drop verticals (installed with secondary insulation) for several locations and for all 4 platforms, is connected together in a "figure 8" arrangement, with single spark gap connection to rail.

REMOVAL OF BONDING

Prior to 1993 all OHW structures had to be bonded by spark gap to rail.

In 1993, an important risk-based assessment for Sydney's electrified network was conducted by experts in the field of risk assessments. As a result, they issued a report entitled "Rail to Mast Bonding Report".

This report recommended that most of the OHW structures *not* be bonded, except at specific "prescribed locations" that had increased risks associated with them (including those at or near all railway stations, etc.).

This assessment was mainly carried out because, at that time, copper theft of bonding wire was on the increase and it was a significant ongoing issue. Reinstating missing or damaged spark gap bonding circuits was probably costing millions of dollars, and it was also redirecting important maintenance effort away from other crucial areas of the electrified network, which could impact reliability and on-time running.

That policy of only bonding certain structures at *prescribed locations* was made about 25 years ago, and since then there have been very few problems (if any). And in the meantime it seems the problem of copper theft (*Section 5.1.27*) has been greatly increasing, driven by the value of copper (see below) – refer to *Section 5.1.26, Some Risks of Live OHW*.

STEEL BONDING CABLE

Leading up to the early 1990s there was a progressively increasing problem with copper theft, especially that of bonding wire, and bonds were installed at every OHW structure in the system, apparently making the temptation too great for some thieves. Refer to *Section 5.1.27*.

In order to deter thieves, it was decided to replace the copper with multi-stranded steel wire with orange plastic insulation covering. An equivalent drawing to the above copper cable bonding arrangement shows the steel bond wire arrangement – drawing EL0011876.

This action made it difficult for thieves to cut the wire, as the hardened steel strands put up a much greater fight against bolt cutters. Steel wire is relatively worthless in short lengths, and to this end it probably worked well.

One main problem with using it was the increased electrical resistivity of steel compared with copper, which meant more thoroughly checking that the total bonding circuit resistance remained low enough to always trip the dc circuit breakers if and when a fault occurred.

The steel wire was also hard to bend into tight situations, thus it that more difficult to install.

But, as mentioned above, probably a better solution was adopted in 1993 when it was no longer required to install bonds at all structures – only those *prescribed locations* with elevated risk required bonding, e.g. at or near stations, etc. Copper should then have been reinstated as the preferred conductor in the reduced number of subsequent bonding situations.

Also, at times a flexible 120mm² multi-strand copper cable with orange insulation was also used in order to lower the circuit resistance for long bonding circuit runs – see *Figure 477* for an instance where both cable sizes were used at the same location.

BOND WIRE IS NOT EARTH WIRE

The colour of the bonding cable insulation must *not* be green or green/yellow, as the bonding wire is *not* an earthing cable, and no one is to wrongly connect an earth wire to it!

This is an important concept that needs to be promulgated to all concerned, particularly electricians, who may be unfamiliar with the significant difference between *bonding a dc system* and *earthing*.

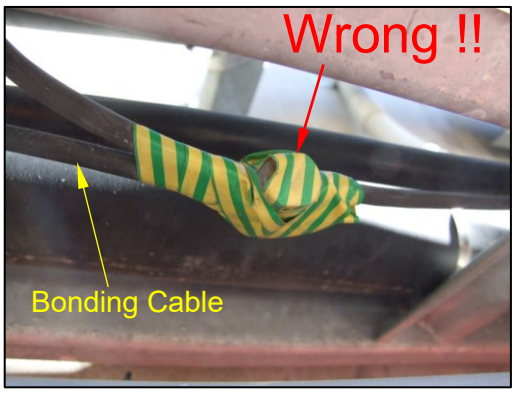


Figure 483 - Green/yellow insulation tape wrongly used in Bonding circuit

Figure 483 shows 2 problems. Someone used green/yellow *earthing* insulation tape to cover a line tap connecting the 95mm² bonding cables in a bonding circuit, which is totally unacceptable. The other issue is that the tape only lasts a few years at best before it disintegrates, especially in the outside environment. The connection should have been housed in a robust UV stabilised plastic case, and then properly secured in place (due to the large dynamic forces that can occur during a fault on this system).

EARTHING OHW STRUCTURES

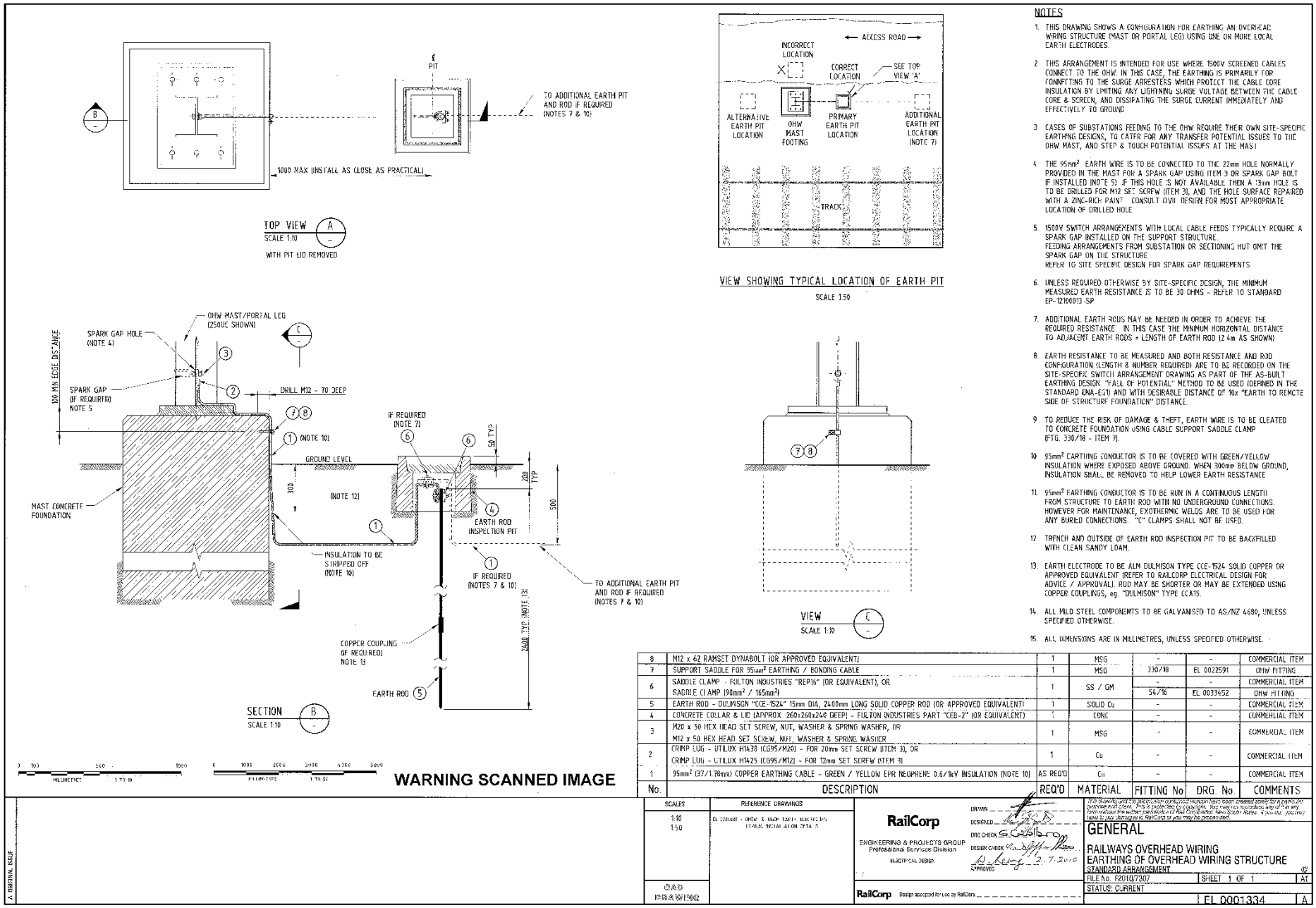
Generally speaking, OHW structures are not earthed. This is in order to minimise the risk of dc leakage currents leaking from structure into the earth and back to the substation this way.

However, if surge arresters are installed on a structure to protect the vital insulation on 1500V screened cables, then this may require the structure to be earthed. Its effective earthing can generally be achieved using the approach given in *Figure 484*. Refer especially to Note 2 on this drawing. The design of such situations requires assessment by experts in Earthing and Bonding in Sydney's dc OHW system and according to the current standards.

RAIL-EARTH CONTACTOR (REC)

Just a note that substations have a "Rail-Earth Contactor" (REC) which is a heavy-current switch that's normally *open*, but closes if the voltage across it exceeds 400V or exceeds 100V for more than 0.5 seconds, likely indicating that something's wrong with the network.

Its function and importance are described further on in *Section 6.1.3*.



NOTES

1. THIS DRAWING SHOWS A CONFIGURATION FOR EARTHING AN OVERHEAD WIRING STRUCTURE (MAST OR PORTAL LEG) USING ONE OR MORE LOCAL EARTH ELECTRODES.
2. THIS ARRANGEMENT IS INTENDED FOR USE WHERE 1500V SCREENED CABLES CONNECT TO THE OHW. IN THIS CASE, THE EARTHING IS PRIMARILY FOR CONNECTING TO THE SURGE ARRESTERS WHICH PROTECT THE CABLE CORE INSULATION BY LIMITING ANY LIGHTNING SURGE VOLTAGE BETWEEN THE CABLE CORE & SCREEN, AND DISSIPATING THE SURGE CURRENT IMMEDIATELY AND EFFECTIVELY TO GROUND
3. CASES OF SUBSTATIONS FEEDING TO THE OHW REQUIRE THEIR OWN SITE-SPECIFIC EARTHING DESIGNS, TO CATER FOR ANY TRANSFER POTENTIAL ISSUES TO THE OHW MAST, AND STEP & TOUCH POTENTIAL ISSUES AT THE MAST
4. THE 95mm² EARTH WIRE IS TO BE CONNECTED TO THE 22mm HOLE NORMALLY PROVIDED IN THE MAST FOR A SPARK GAP USING ITEM 3 OR SPARK GAP BOLT IF INSTALLED (NOTE 5). IF THIS HOLE IS NOT AVAILABLE THEN A 13mm HOLE IS TO BE DRILLED FOR M12 SET SCREW (ITEM 3), AND THE HOLE SURFACE REPAIRED WITH A ZINC-RICH PAINT. CONSULT CIVIL DESIGN FOR MOST APPROPRIATE LOCATION OF DRILLED HOLE
5. 1500V SWITCH ARRANGEMENTS WITH LOCAL CABLE FEEDS TYPICALLY REQUIRE A SPARK GAP INSTALLED ON THE SUPPORT STRUCTURE. FEEDING ARRANGEMENTS FROM SUBSTATION OR SECTIONING HUT OMIT THE SPARK GAP ON THE STRUCTURE. REFER TO SITE SPECIFIC DESIGN FOR SPARK GAP REQUIREMENTS
6. UNLESS REQUIRED OTHERWISE BY SITE-SPECIFIC DESIGN, THE MINIMUM MEASURED EARTH RESISTANCE IS TO BE 30 OHMS - REFER TO STANDARD EP-12100013 SP
7. ADDITIONAL EARTH RODS MAY BE NEEDED IN ORDER TO ACHIEVE THE REQUIRED RESISTANCE. IN THIS CASE THE MINIMUM HORIZONTAL DISTANCE TO ADJACENT EARTH RODS = LENGTH OF EARTH ROD (2.4m AS SHOWN)
8. EARTH RESISTANCE TO BE MEASURED AND BOTH RESISTANCE AND ROD CONFIGURATION (LENGTH & NUMBER REQUIRED) ARE TO BE RECORDED ON THE SITE-SPECIFIC SWITCH ARRANGEMENT DRAWING AS PART OF THE AS-BUILT EARTHING DESIGN. "FALL OF POTENTIAL" METHOD TO BE USED (DEFINED IN THE STANDARD ENA-EG1) AND WITH DESIRABLE DISTANCE OF 10x "EARTH TO REMOTE SIDE OF STRUCTURE FOUNDATION" DISTANCE.
9. TO REDUCE THE RISK OF DAMAGE & THEFT, EARTH WIRE IS TO BE CLEATED TO CONCRETE FOUNDATION USING CABLE SUPPORT SADDLE CLAMP (RTG. 330/18 - ITEM 7).
10. 95mm² EARTHING CONDUCTOR IS TO BE COVERED WITH GREEN/YELLOW INSULATION WHERE EXPOSED ABOVE GROUND. WHEN 300mm BELOW GROUND, INSULATION SHALL BE REMOVED TO HELP LOWER EARTH RESISTANCE
11. 95mm² EARTHING CONDUCTOR IS TO BE RUN IN A CONTINUOUS LENGTH FROM STRUCTURE TO EARTH ROD WITH NO UNDERGROUND CONNECTIONS. HOWEVER FOR MAINTENANCE, EXOTHERMIC WELDS ARE TO BE USED FOR ANY BURIED CONNECTIONS. "C" CLAMPS SHALL NOT BE USED.
12. TRENCH AND OUTSIDE OF EARTH ROD INSPECTION PIT TO BE BACKFILLED WITH CLEAN SANDY LOAM.
13. EARTH ELECTRODE TO BE ALM DULMISON TYPE CCE-1524 SOLID COPPER OR APPROVED EQUIVALENT (REFER TO RAILCORP ELECTRICAL DESIGN FOR ADVICE / APPROVAL). ROD MAY BE SHORTER OR MAY BE EXTENDED USING COPPER COUPLINGS, eg. "DULMISON" TYPE CCA1S.
14. ALL MILD STEEL COMPONENTS TO BE GALVANISED TO AS/NZ 4680, UNLESS SPECIFIED OTHERWISE.
15. ALL DIMENSIONS ARE IN MILLIMETRES, UNLESS SPECIFIED OTHERWISE.

No.	DESCRIPTION	REQ'D	MATERIAL	FITTING No	DRG. No.	COMMENTS
8	M12 x 62 RAMSET DYNABOLT (OR APPROVED EQUIVALENT)	1	MSG	-	-	COMMERCIAL ITEM
7	SUPPORT SADDLE FOR 95mm² EARTHING / BONDING CABLE	1	MSG	330/18	EL 0022591	OHW FITTING
6	SADDLE CLAMP - FULTON INDUSTRIES "REP16" (OR EQUIVALENT), OR SADDLE CLAMP (90mm² / 165mm²)	1	SS / GM	- / 54/16	- / EL 0033452	COMMERCIAL ITEM / OHW FITTING
5	EARTH ROD - DULMISON "CCE-1524" 15mm DIA, 2400mm LONG SOLID COPPER ROD (OR APPROVED EQUIVALENT)	1	SOLID Cu	-	-	COMMERCIAL ITEM
4	CONCRETE COLLAR & LID (APPROX. 260x260x240 DEEP) - FULTON INDUSTRIES PART "CEB-2" (OR EQUIVALENT)	1	CONC	-	-	COMMERCIAL ITEM
3	M20 x 50 HEX HEAD SET SCREW, NUT, WASHER & SPRING WASHER, OR M12 x 50 HEX HEAD SET SCREW, NUT, WASHER & SPRING WASHER	1	MSG	-	-	COMMERCIAL ITEM
2	CRIMP LUG - UTILUX H1438 (CG95/M20) - FOR 20mm SET SCREW (ITEM 3), OR CRIMP LUG - UTILUX H1425 (CG95/M12) - FOR 12mm SET SCREW (ITEM 3)	1	Cu	-	-	COMMERCIAL ITEM
1	95mm² (37/1.78mm) COPPER EARTHING CABLE - GREEN / YELLOW EPR NEOPRENE 0.6/1kV INSULATION (NOTE 10)	AS REQ'D	Cu	-	-	COMMERCIAL ITEM

SCALES: 1:10, 1:50

REFERENCE DRAWINGS: EL 2284-08 - OHW & 1500V EARTH - ELECTRICITY - PUBLIC INSTALLATION DETAILS

RailCorp ENGINEERING & PROJECTS GROUP Professional Services Division ELECTRICAL DESIGN

DRAWN, DESIGNED, DRG CHECK, DESIGN CHECK, APPROVED 2.7.2010

RailCorp Design accepted for use by RailCorp

GENERAL

RAILWAYS OVERHEAD WIRING EARTHING OF OVERHEAD WIRING STRUCTURE STANDARD ARRANGEMENT

FILE No. F2010/7307 SHEET 1 OF 1 A1

STATUS: CURRENT

EL 0001334 A

A ORIGINAL ISSUE

CAD DRAWING

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Figure 484 - Earthing of OHW Structure drawing

CARE WITH BONDING CIRCUITS

Particular care is needed with bonding circuits in relation to any steel reinforced concrete, as excessive leakage currents from the bonding circuit into the mostly hidden steel strands can corrode them and thus reduce the structural integrity of the structure (e.g. overline bridge).

Fasteners typically require drilled holes into the concrete for the installation of anchor rods, and these rods need to avoid permanently touching the steel reinforcing rods. Unfortunately, this is all hidden from view, and it's difficult to confirm that this isolation has been achieved in all cases.

However, sometimes a special "Test Point" can be established, that electrically connects to the steel reinforcing during construction of the concrete structure, to test for correct isolation in this situation.

Alternatively, special epoxy-coated insulated stainless steel anchor bolts (e.g. the Hilti "HIT- BAR" or equivalent) are ideal in this situation. The roughened thick (green) epoxy coating on the stainless steel threaded rod, when embedded into an enlarged hole in concrete and glued with other epoxy, ensures that any connected parts of the bonding circuit cannot possibly connect with the embedded steel reinforcing rods. It also provides excellent mechanical anchorage. Perfect. *Figure 485*.

Figure 485 - Hilti "Hit-Bar"

3.12.0.6 Status (c. 2014)

Bonding designs are to be to the current Standard, and are to be developed and signed off by persons with the appropriate Engineering Authority to do so.

3.12.0.7 Reference

See *Table 43* for drawings of bonding arrangements. Also, refer to:

- Standard EP-12200001-SP, "Bonding of Overhead Wiring Structures to Rail" for prescribed locations that require bonding.
- Standard EP-08160002-SP, "Safety Barriers for OHW Structures".
- Standard EP-08000007-SP, "Safety Screens for Bridges Over 1500V Equipment".

Section 5.1.26, Some Risks of Live OHW may have more information.

For information on various bonding schemes, etc. refer to my document "North Sydney – Proposed OHW Bonding Policy", dated 14/7/2013.

IMPORTANT

Reference must be made to the current electrical standards when designing bonding arrangements. These Standards may, over time, alter the approved bonding approaches and/or require different outcomes to that described above.

Also, as mentioned above, all bonding designs must be developed and signed off by persons with the appropriate Engineering Authority to do so.

Unusual situations require someone with significant Earthing & Bonding expertise in the dc rail environment, to help direct the design, and to ultimately check / verify the resulting design drawings.

4 OHW Systems

This chapter introduces various Sydney OHW systems that are mostly in use today, along with some older systems which may have been replaced over the recent years to modernise the electrified network and bring about improved reliability. It's intended to describe each of the main systems, but more importantly it looks at the salient characteristics of each – both the good and the bad.

This chapter is divided into the 2 main sections, based on the means of tensioning the OHW conductors, i.e. *Fixed-Anchored OHW Systems* and *Regulated OHW Systems*. This approach was adopted because the most fundamental character of an OHW system is associated with the way it's tensioned, i.e. whether the tension varies with temperature (which is simple and cheaper to build, and has other advantages), or if it remains relatively constant with temperature (which is ideal) – respectively.

It also includes a small third section: the *Conductor Rail System* (which is under no tension). However, I admit that I have had very little experience with this recent system to Sydney, and it wasn't included in the original TMP assessment process in the 1990s because it didn't exist for Sydney back then.

Refer to *Table 44* for a summary of the various main fixed-anchored and regulated OHW systems in Sydney. Each has been given an OHW System ID number, which is shown in the left column in this table. The ID number has no chronological significance (it was mostly established based on my progressive exposure to the various OHW systems over the years). The same ID number is included in the various standards.

Refer to EP-08000016-SP, "Designations of OHW Conductor Systems" for details of each OHW system in Sydney's network – both present and obsolete.
Refer also to EP-08000017-SP, "Overhead Wiring Conductor System Selection", which describes how to choose an OHW system.
These standards include a few of the more obscure and less used OHW systems, that may not be documented here.

The table shows the relevant OHW conductor configurations at a glance, including catenary and contact wire sizes and tensions. For the all-important contact wire, it shows its metal composition: hard-drawn copper, cadmium copper or tin-bearing copper.

Also shown are the *System* details, and especially the standard *Loaded Catenary T/w* values. The higher this number is, the tighter the catenary wire is, giving less mid-bay sag and generally resulting in better dynamic performance with higher train speeds (although this also depends on the contact wire tension, with the same applying).

Lastly, the table gives an idea of the approximate time of initial construction for about half the systems.

Note that this table has not been updated since about 2007, and much modernisation work has been carried out over the past 2 decades, mostly in order to:

a) *Renew any aged infrastructure.* It was particularly important to renew the contact wire, as this is one of the few main items that wears over time (with frictional sliding contact against the carbon strips of millions of pantograph passages). Also, the OHW structures were often rusted beyond economic repair.
b) *Regulate the conductors*, where it was deemed achievable without costing too much. Regulating the wires provided many benefits, including a much increased current carrying capacity, better contact wire/pantograph interaction at speed, more predictable performance in windy conditions, increased periods between maintenance cycles (reducing ongoing costs), etc.

c) *Provide "Independent Registration"*, for cases of OHW support & registration equipment spanning 2 or more tracks. Implementing this policy meant that any damage to the OHW on one track was much less likely to involve/affect the OHW for adjacent tracks. This was an important decision made in the late 1980s, and one that was made with a lot of persistence and determination from the organisation. It was done primarily to improve the operational reliability of the OHW systems, and bring about quicker repairs in case the OHW became damaged (e.g. due to a pantograph incident), so trains could recommence operations as soon as possible with the least inconvenience to travelling customers and freight operations (back then).

With Sydney's various OHW systems, both the catenary and contact wires are tensioned by the *same mode*, i.e. they are either both fixed-anchored or both regulated tension.

Various overseas traction systems have examples where they have decided to regulate one wire and leave the other wire as fixed-anchored, and this is probably done for a number of reasons, including to save money. For instance:

- *Regulating the catenary wire only*. This helps control the overall height of the fixed-anchored contact wire, especially approaching mid-bay, under the extreme hot and cold temperatures.
  However, the down side is the amount of contact wire ripple (sag between droppers) that the pantograph still has to cope with, and the additional blowout under windy conditions, both as a consequence of the fixed-anchored low tension at hot temperatures. If the system is installed underground with no crosswind, there may be good justification for using this mode.
- *Regulating the contact wire/s only*. This helps to control the contact wire running profile (with less ripple between droppers) and to reduce the amount of blowout with wind.
  The down side to this is that the fixed-anchored catenary wire will alter the mid-bay contact height fairly dramatically, resulting in mid-bay contact heights that are higher at cold temperatures and lower in hot conditions. This would likely limit the train speeds, and care is needed to ensure that the contact wire doesn't touch the roof of a train under hot conditions. Also, under high wind and hot conditions, the catenary will blow out much further at mid-bay and so may tend to drag the regulated contact further away from track because of the regularly spaced connecting droppers. But again, it's a way of reducing costs and may be appropriate under certain circumstances. (This might be especially true in underground situations where it's often difficult to support a regulated catenary wire in a way that allows for its longitudinal movement with temperature.)

Regulating just the contact wire/s is probably easier to achieve than just the catenary.

One negative aspect to both the above situations is that the droppers should ideally be designed to be able to move longitudinally if the regulated catenary wire moves but the fixed-anchored contact wire doesn't move (and vice versa). Droppers that don't remain vertical can affect the contact wire profile which can thus adversely affect smooth pantograph current collection.

As mentioned, Sydney has not adopted the above approach, so the catenary and contact wires are either both fixed-anchored or both regulated. I understand this policy was intended to avoid the complications of getting it right during design, construction and maintenance, and without inadvertently causing any insidious fatigue problems later on.

The "current" OHW systems for all new construction are (or at least were in 2014) limited to those shown in orange highlight in the below table.

ID No.	Location (where used)	Catenary Size (mm²)	Catenary Tension (kN)	Aux. Catenary Size (mm²)	Aux. Catenary Tension (kN)	Contact Size (mm²)	Contact Tension (kN)	Contact Metal [1]	System Tension Mode [2]	System Weight (N/m)	System T/w (m)	Approx. Year Installed	Comments
	Regulated Systems												
1	Gosford to Newcastle	**327**	16.50	-	-	**193**	16.50	HD Cu	Regulated	48.0	344	1982-84	
2	Waterfall to Pt Kembla	**270**	30.00	-	-	**2x137**	12.50	HD Cu	Regulated	51.0	588	1985	Standard twin-contact regulated system.
3	Liverpool to Glenlee	**270**	17.80	-	-	**2x137**	11.12	HD Cu	Regulated	51.0	349	1968	
4	Loftus to Waterfall	**270**	15.60	-	-	**193**	15.60	HD Cu	Regulated	42.0	371	1980	
5	ESR Viaducts	**270**	19.43	-	-	**2x137**	9.72	HD Cu	Regulated	51.0	381	1979	
6	Kingsgrove	**270**	19.00	-	-	**193**	16.00	HD Cu	Regulated	42.0	452	1991	
7	Metropolitan Upgrade	**510**	34.60	-	-	**193**	18.00	HD Cu	Regulated	62.9	550		
8	Metropolitan Upgrade	**327**	26.40	-	-	**193**	18.00	HD Cu	Regulated	48.0	550		
9	Metropolitan Upgrade **	**270**	23.10	-	-	**193**	18.00	HD Cu	Regulated	42.0	550		Standard single-contact regulated system.
10	Metropolitan Upgrade **	**165**	18.15	-	-	**193**	18.00	HD Cu	Regulated	33.0	550		Standard single-contact regulated system.
12	Metropolitan Upgrade **	**2x270**	20.35	-	-	**2x137**	12.50	HD Cu	Regulated	74.0	550	1990	Twin-Caty/Twin-Contact regulated system.
13	Coalcliff Tunnel	**2x270**	19.00	-	-	**2x193**	16.00	HD Cu	Regulated	84.0	452	1986	Coalcliff Tunnel (only)
14	Newnes Balloon Loop	-	-	-	-	**193**	11.80	HD Cu	Regulated	16.9	-		
15	Metropolitan Upgrade **	**2x165**	15.40	-	-	**2x137**	12.50	HD Cu	Regulated	56.0	550	2006	Twin-Caty/Twin-Contact regulated system.
	Fixed-Anchored Systems												
21	Metropolitan	**270**	15.90	-	-	**193**	13.35	Cad Cu	Fixed	42.0	379		
22	City Tunnels	**270**	14.15	-	-	**137**	9.34	Cad Cu	Fixed	37.1	381		
23	Hornsby to Gosford	**327**	17.92	-	-	**193**	13.35	Cad Cu	Fixed	47.0	381	1958	Mostly removed
24	Hornsby to Gosford	**510**	24.11	-	-	**193**	13.35	Cad Cu	Fixed	63.3	381	1958	Mostly removed
25	Metropolitan X-Overs	**165**	12.37	-	-	**193**	13.35	Cad Cu	Fixed	32.5	381		
26	Metropolitan X-Overs	**165**	10.99	-	-	**137**	12.46	Cad Cu	Fixed	28.8	382		
27	Penrith to Bowenfels	**327**	19.94	**179**	6.61	**193**	13.35	Cad Cu	Fixed	66.0	302	1957	Compound OHW System
28	ESR & NSR Tunnels **	**270**	19.43	-	-	**2x137**	9.35	Cad Cu	Fixed	51.0	381	1979	ESR (1979), NSR (2000) & ECRL (2007) [3]
29	Tempe to Loftus	**270**	17.85	-	-	**2x137**	12.50	Cad Cu	Fixed	51.0	350	1990	
33	Yards (Steel Catenary)	**91 steel**	9.52	-	-	**193**	13.35	Cad Cu	Fixed	25.0	381		
34	Yards (Steel Catenary)	**91 steel**	7.92	-	-	**137**	9.30	Cad Cu	Fixed	20.0	396		
35	Mortdale to Sutherland	**270**	18.80	-	-	**2x137**	12.48	Cad Cu	Fixed	51.0	365	c. 1980 ?	Illawarra Upgrade at Mortdale to Sutherland
36	Sydney Yard	-	-	-	-	**193**	13.35	Cad Cu	Fixed	16.9	-		Sydney Yard

Notes : (Refer to EP-08000016-SP - "Designations of OHW Conductor Systems")

1. "**Contact Metal**" can be :
   - HD Cu (Hard Drawn Copper) for Regulated Systems only.
   - Cad Cu (Cadmium Copper) for Fixed Anchored Systems only.
   - Tin Cu (Tin Bearing Copper) for Fixed Anchored Systems only (for new work).
2. "**Tension Modes**" can be :
   - Reg10 (Regulated Tension).
   - Fixed (Fixed Anchored)
3. Tunnels:
   - "ESR" - Eastern Suburbs Railway (1979)
   - "NSR" - New Southern Railway {Airport Line} (2000)
   - "ECRL" - Epping to Chatswood Rail Line (2007)

** - OHW Systems for future Electrification

Table 44 - List of past & present OHW Systems

4.1 FIXED-ANCHORED OHW SYSTEMS

4.1.0 General

Fixed-anchored OHW systems were the first to be introduced to Sydney, in the 1920s.

They are simple in construction and include relatively cheap support & registration arrangements. However, they need to be properly designed to cope with the wide tension fluctuations with extreme temperatures – both hot and cold – to provide reliable train services.

One particular fixed-anchored OHW system is still being used for new infrastructure – the twin contact "tunnel" OHW system (OHW System 28). Examples include the Airport Tunnel opening in 2000 and Epping to Chatswood Tunnels in 2007.

The concept of "Virtual Span" plays an important role when designing or altering any fixed-anchored OHW. It's extremely important to have a good working understanding of the consequences of changing *virtual span*, particularly on the catenary wire. Simple changes in supported catenary locations in the field can have a profound effect on its tension behaviour with temperature changes. And this can lead to problems several bays or more away from where a change is made!

Indeed, fixed-anchored systems used pull-offs within each bay as a way to maximise the bay length (from catenary support to next catenary support) and thus increase the virtual span number, which then makes the OHW tension behave better. Most bays used at least 1 pull-off (at mid-bay), but up to 3 pull-offs could be employed in bays around tight track curves (achieving long 73m bay lengths).

It is important that the catenary tension remains per design throughout the wire run. Any slippage of fittings or other mechanisms that reduced this tension could result in *low contact wire at mid-bay*, particularly in long bays and under hot conditions. The minimum contact height of 4.57m under any condition, was the standard that had to be generally met.

There have been many examples in the past where people have, either deliberately or inadvertently, caused a reduction of the catenary virtual span in an area, without its effect on catenary tension being checked out, and resulted in some (often significant) problem to running trains. This VS change can be brought about by simply locking a catenary from longitudinal movement where it previously had such freedom.

Problem Example:

Auburn, January 2012 – Electrical Investigation Report ER0625.

Changes to a fixed-anchored OHW run were made without checking its effect on another nearby but connected fixed-anchored catenary wire run. The changes caused the catenary virtual span to *decrease*. This resulted in lower tensions, and a feeder clamp lowering down during hot weather to the level of the in-running contact wire per *Figure 486*. And this caused some pantographs to strike this clamp and become damaged, as indicated in *Figure 487* (I think the damage to the pantograph/s was noted at Lithgow, more than 100km away). It was difficult to find the problem

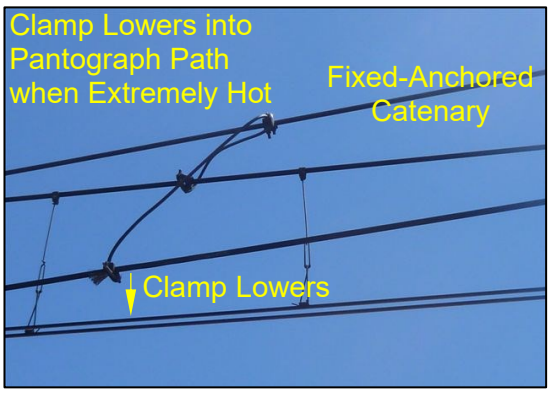


Figure 486 - Clamp clashes with pantograph when OHW is hot

because the clamp moved up when the wire was slightly cooler, to show quite an innocent situation.

Refer to the subsequent document, "Electrical Investigation Report", ER0625, for more information.

Figure 487 - Resulting Pantograph damage

Because of the extremely high contact tensions under cold conditions, the contact wire needs to be made of a hard copper alloy. I understand that initially this metal was standardised as cadmium-copper which worked well. Due to manufacturing issues, this was change in about the 1990s to tin-copper which is almost hard and as strong in tension.

Because the contact wire wears in time, its condemning size (remaining cross-sectional area) is fairly critical. If the contact wire run uniformly wears down to this limit, then the entire run needs to be renewed. If it wears down to this size only in certain localised points (e.g. "hard spots" at pull-off arms), then short sections can be renewed using full-splices (to install short lengths of new wire). Alternatively, "wear strips" can be added in parallel to the worn wire to prevent any further wear. For more details, see *Section 3.1.2.5, Condemning Size*.

The simple catenary system has been a most popular OHW system, both here and elsewhere in the world. A catenary wire with its parabolic shape, supports the contact wire with its flat shape, by means of droppers spaced (in Sydney's case) about every 4.57m (15 feet). (Contrast this dropper spacing with that for regulated contact wire which is up to 8m.)

These fixed-anchored systems include 1 catenary wire supporting 1 or 2 contact wires. Sometimes an auxiliary feeder wire, the same size as the catenary, is added to the side of the catenary wire, and takes on the same *T/w* parabolic shape and sag.

The standard contact height was 5.03m (16'-6").

Sydney seemed to generally standardise on a loaded catenary *T/w* of 381m (actually 1,250ft in the imperial system). And this was regardless of the catenary size or contact size, and whether single or twin contact was supported. This seemed to give a practical depth of sag for the large bays in use back then (up to 73m long). Bear in mind that the contact wire height towards mid-bay (resulting mostly from the sag of a hot, low tension catenary) had to remain well above the 4.57m minimum value under the hottest conditions (which is 150mm above the roof of trains). And the catenary wire had to have at least 3:1 safety factor under the highest temperatures from coldest temperatures (with relevant virtual span figures applied).

The big benefit of this standardise *T/w* strategy was that the dropper lengths were the same for any particular bay length. So, with the use of a special "Dropper Board", any bay of droppers could be quickly determined and made, ready for installation in the field.

Finally, over the past almost 100 years, other than the above problem with virtual span, most of the fixed-anchored OHW systems have proven to be quite reliable, probably due to their inherent simplicity (but also because any problem areas were improved and refined over much time). And as a testament to this, some of the older systems are still in service today, and they're not causing any inherent problems (provided there's not too much current demanded from trains now).

4.1.1 Metropolitan Simple Catenary OHW System

CONDUCTORS

This "Simple Catenary" OHW system was the one initially installed in Sydney, and it was probably the most widespread configuration installed in the early days throughout the electrified network, probably because of its relative simplicity and low cost.

I think the most popular *catenary* wire size was the 270mm² (0.4 in²) copper wire for *main lines* and 165mm² (0.25 in²) for *crossovers* and *sidings*. Steel catenary was sometimes used in yards (and some yards still have this catenary wire e.g. Penrith Yard as at 2014). Note that the initial 270mm² catenary wire had many more and finer strands – 61/2.36mm, compared to the one used today – 37/3.05mm. See *Section 3.1.1.4* and *Section 3.1.1.5*, *Wire Stranding* for more details on this.

I'm not sure, but there may have been some odd *contact* wire sizes in the very early days of electrification, because the railways used to maintain Sydney's tram system too (which I was told used "phono" wire sizes). But predominantly the contact wire was initially 137mm² (0.2 in²), and later in the 1950s the 193mm² (0.3 in²) was introduced, both made from cad-copper. As described in *Section 3.1.2.5*, *A Contact Wire with a Problem*, the larger 193mm² size was later deemed less suitable because any contact kinks were extremely difficult to fully remove, leading to some significant pantograph arcing. And, although it could carry more current than its smaller cousin, it took longer to cool down after being heated by train currents (which these days is a bad effect). The superior outcome was to have twin 137mm² contacts instead, and this configuration became popular in certain areas as well.

Standard contact height was 5.03m (16'–6"). Various other details are given back in *Table 7*.

SUPPORT & REGISTRATION

This early fixed-anchored OHW system is characterised by tall portal structures with multiple span wires that crossed the tracks form one portal leg to the opposite leg. These supported and registered all the OHW loads. Also, it was usual to have one or more mid-bay pull-off locations, with masts and cross span configurations that registered the contact and catenary wires but did not support them. See *Figure 236* much further back for an idea of the various parts that make up a typical portal suspension arrangement (for 3 tracks).

As I understand it, the primary reasons for mid-bay *pull-offs* were as follows.

- To *maximise the catenary virtual span*. This helped keep the catenary tension excursions to a minimum under the hot and cold extremes. And it led to less structure steelwork, since pull-off structure did not require portal bridges spanning the tracks.
- Having 1, 2 or even 3 pull-offs in a bay helped *control the contact wire blowout*, especially under hot temperature (low tension) conditions.
  Straight tracks with very long bays often needed 1 pull-off to control the mid-bay contact lateral positioning, so that it remained on the pantographs throughout the bay, especially when the wire was blown out under windy conditions, i.e. *pantograph security*.
  And on curved track there might be 2 pull-offs, while tight curves sometimes had 3 pull-offs, again for the same reason. But in all cases, long bay lengths resulted in desirable large catenary virtual spans (bringing all its benefits).

Figure 488 is a photo of some old fixed-anchored OHW, including several pull-offs and suspension arrangements. This is for the winding single track that leads suburban trains down to (and back from) Lavender Bay Sidings (for non-peak train stabling).

Figure 488 - Old Fixed-Anchored OHW (single track to Lavender Bay)

Although there were probably many early fixed-anchored support & registration arrangement drawings, the ones shown in the following 6 standard arrangement drawings are the most recent and important (I think) – *Figure 489* to *Figure 494*.

The first 3 arrangements show the various ways the OHW is *supported and registered*, (in order of increasing contact radial load – in the right-hand direction), while the last 3 show how they are registered only using *pull-offs* (again in order of increasing contact radial load). Note that they unfortunately show "Rail Level" as the higher of the 2 rails of a track (for whatever reason), whereas these days *Rail Level* is defined as the *lower* of the 2 rails of a track.

For straight track, the radial load was only due to the zig-zag staggering through each bay (for less pantograph wear), and this low radial load meant that cheap and simple *straight arms* were able to be used, along with a large *heel height* (of about 400mm!). Any added wind loading didn't really cause a problem. See further back to *Figure 197* for instance.

Even though the contact cross-span is about 400mm above the contact wires of each track, all arrangements employed a *fender* installed on the top of the contact wire and located directly below this contact cross-span. This fender was there to limit the amount that the contact wire lifted when the closely-spaced pantographs of multiple-header electric locomotives came along, and especially under hot conditions when the contact tension plummeted (to less than 2kN!). This was a particularly bad combination – in a static sense, even 1 pantograph can lift the contact wire by about 70mm. But many closely spaced pantographs, each assisting the other, will increase the uplift to much higher values (compounding the problem), and could ultimately strike the cross-span and bring the OHW down for all tracks affected. Thus the need for the fender, which pushes up against the tight cross-span if too much uplift is experienced, to then control the height. See *Section 3.1.2.5, Contact Uplift with Pantographs* for more details. See also *Figure 239*.

Vertical spreader bars were employed where the radial loads were higher, and this was needed to get the heel height down to a suitable level so as to not cause localised contact wire uplift from such high radial loads.

There are no electric locomotives these days, so this is no longer a problem, and the far greater pantograph spacing on the passenger fleet should not pose a problem here.

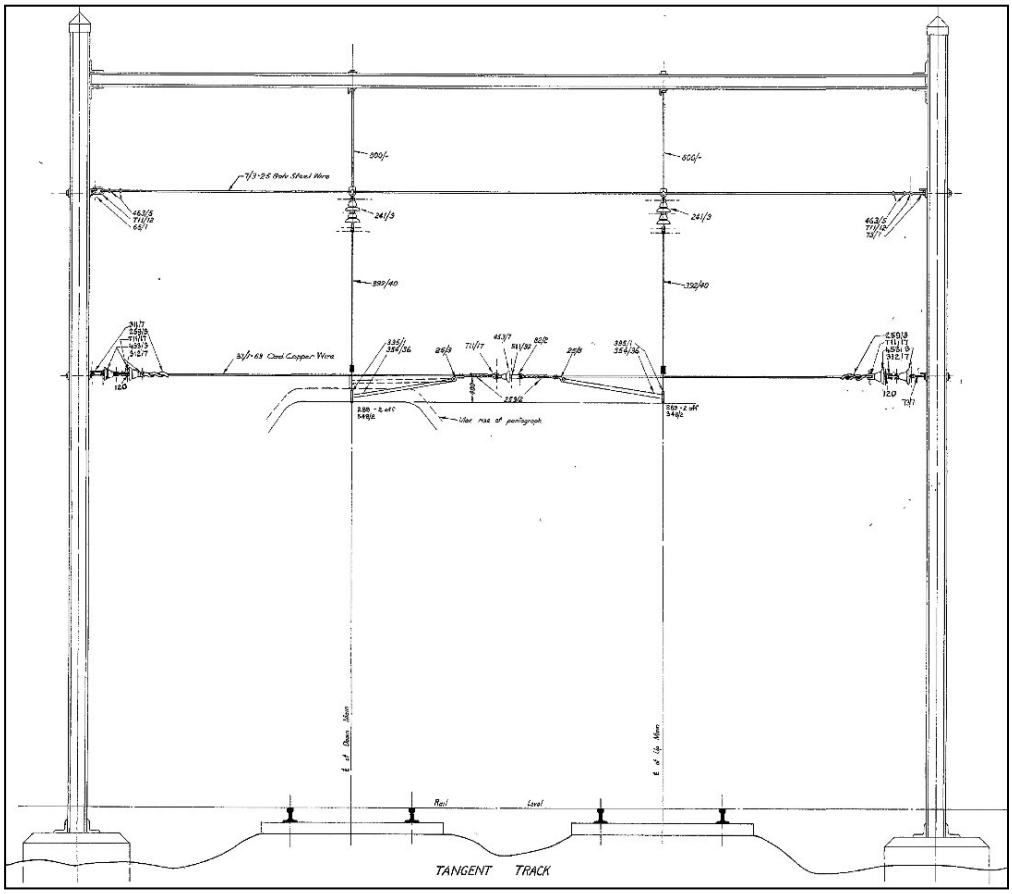


Figure 489 - Fixed-Anchored S&R on straight track (stagger load)

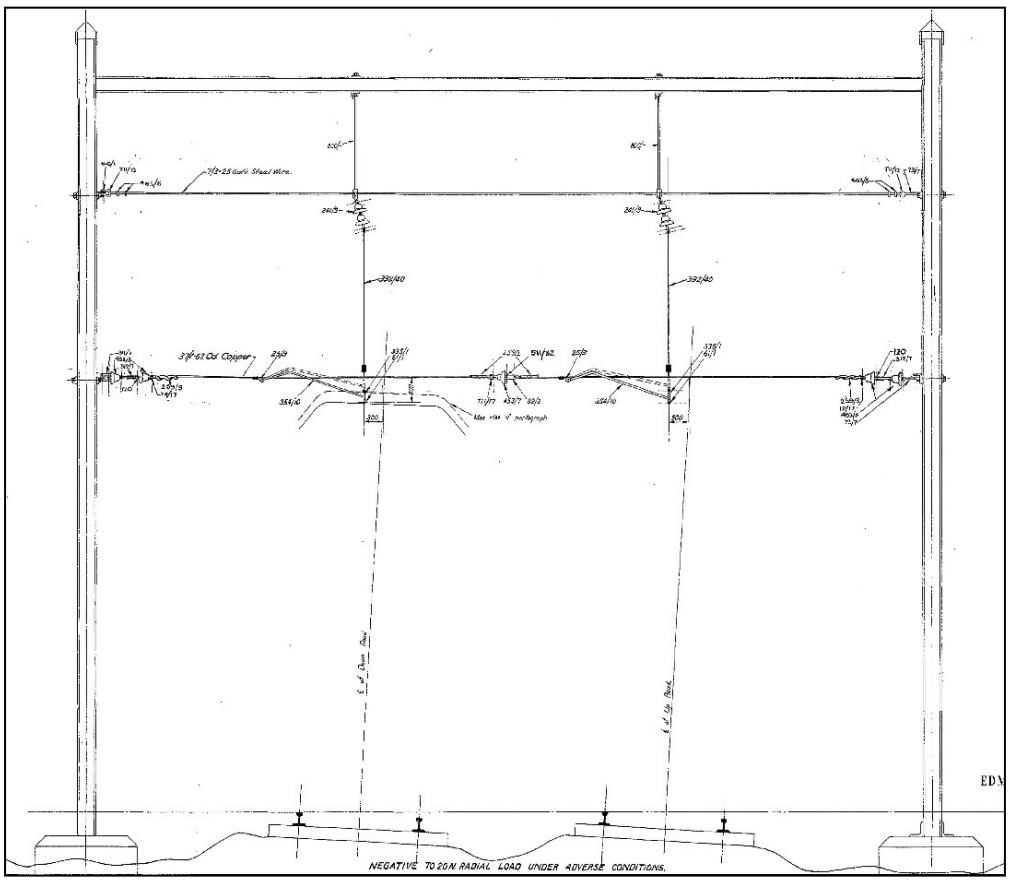


Figure 490 - Fixed-Anchored S&R on slight track curves (medium RL)

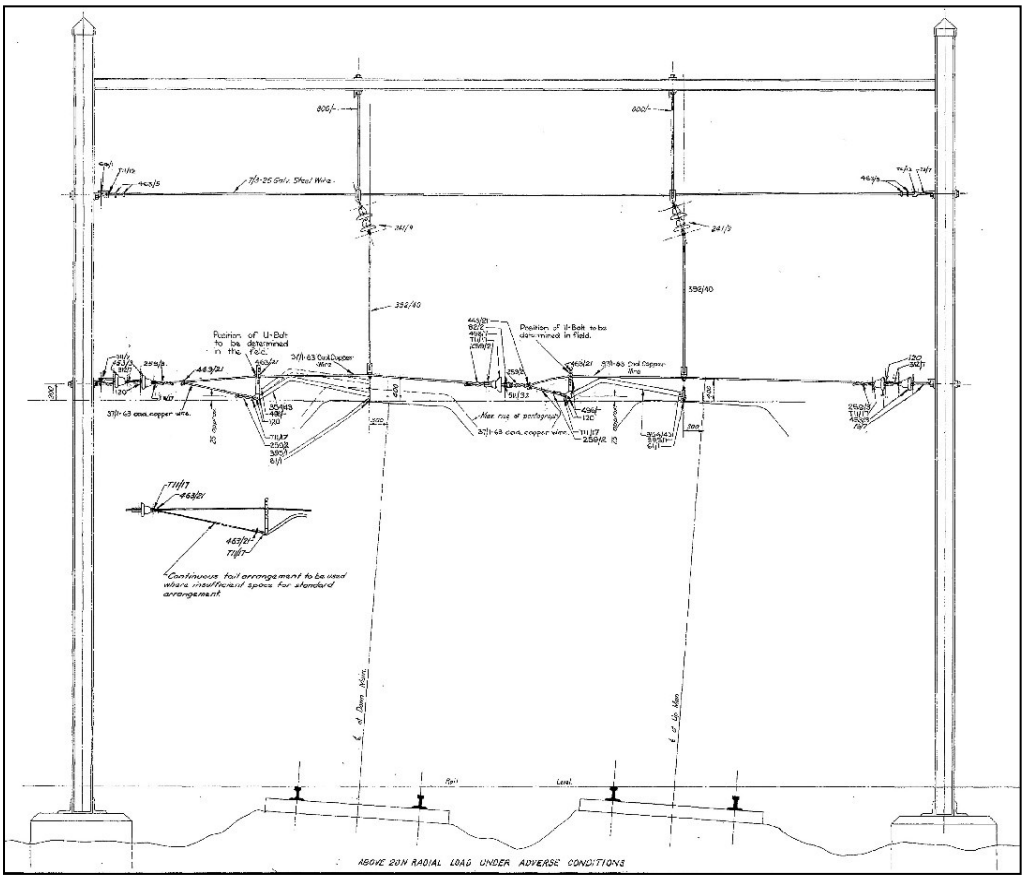

Position of U-Bolt to be determined in f.c.
Position of U-Bolt to be determined in field.
Continuous foil arrangement to be used where insufficient space for standard arrangement
ABOVE 20N RADIAL LOAD UNDER ADVERSE CONDITIONS

Figure 491 - Fixed-Anchored S&R on tight track curves (high RL)

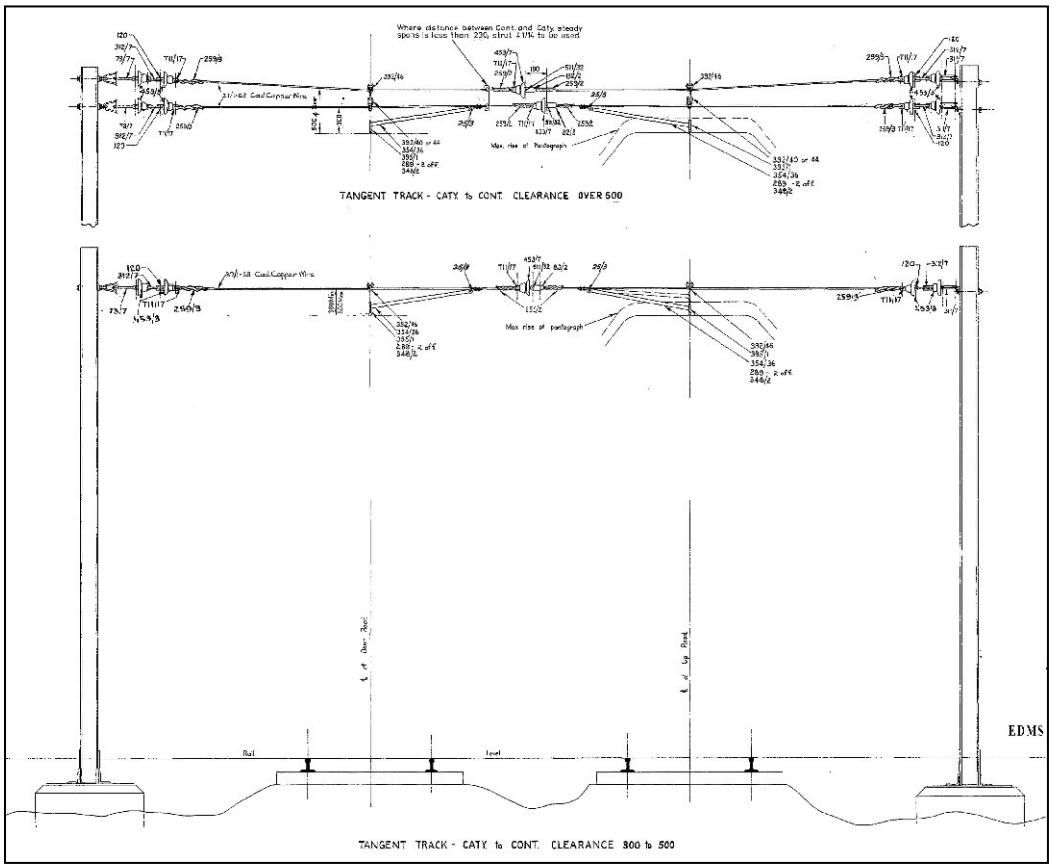


Figure 492 - Fixed-Anchored Pull-Off on straight track

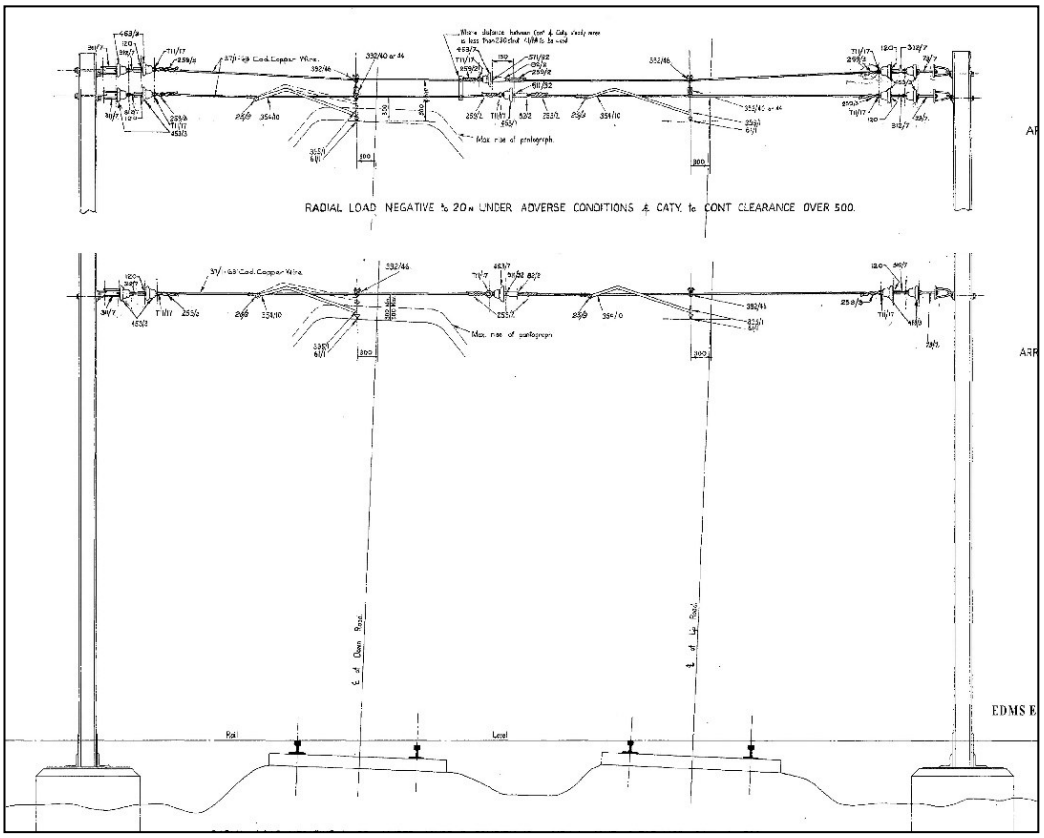

RADIAL LOAD NEGATIVE to 20 kN UNDER ADVERSE CONDITIONS & CATY. to CONT CLEARANCE OVER 500.
Max rise of pantograph.
℄ of Down Road
℄ of Up Road
Rail
Level

Figure 493 - Fixed-Anchored Pull-Off on slight track curves (low RL)

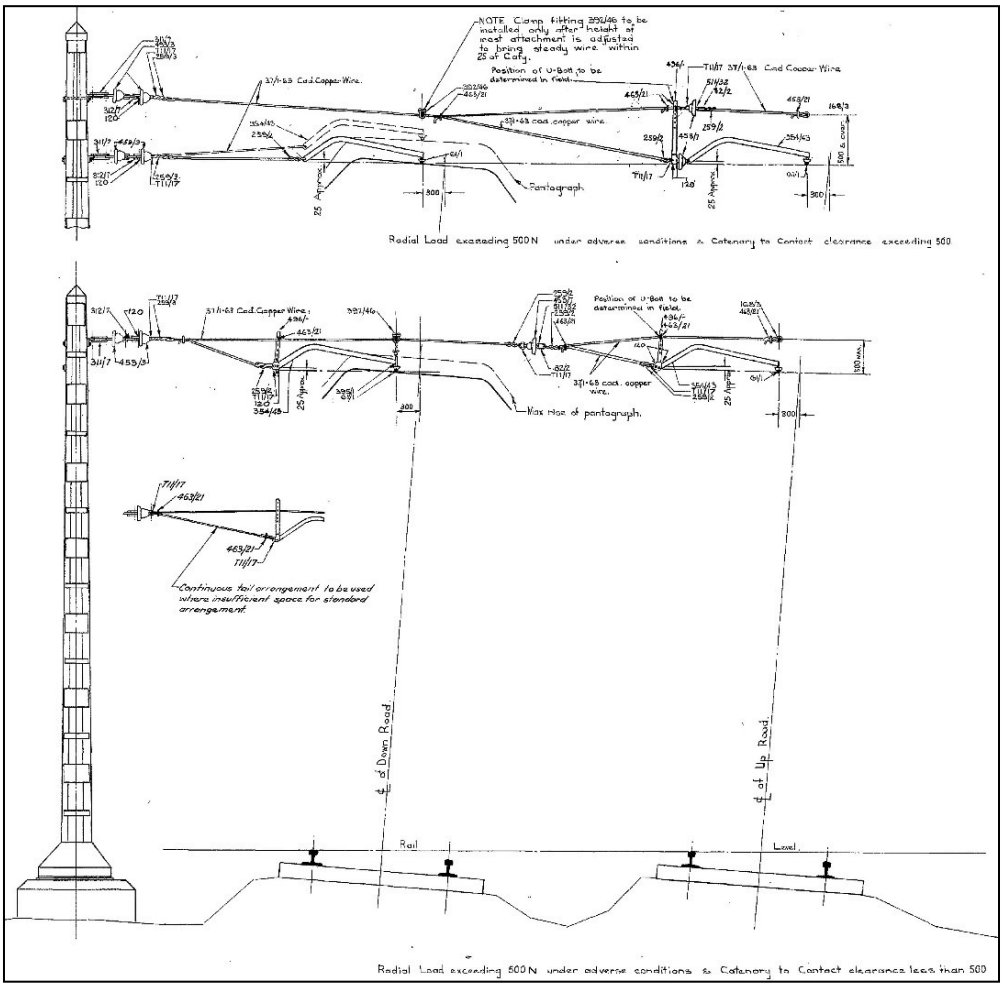

NOTE Clamp fitting 354/46 to be installed only after heldet at most attachment is adjusted to bring steady wire within 25 of Caty.
Position of U-Bolt to be determined in field.
37/1-68 Cad.Copper Wire.
37/1-68 cad. copper wire.
Pantograph.
Radial Load exceeding 500N under adverse conditions & Catenary to Contact clearance exceeding 500
Max rise of pantograph.
Continuous tail arrangement to be used where insufficient space for standard arrangement.
℄ of Down Road
℄ of Up Road
Rail
Level
Radial Load exceeding 500N under adverse conditions & Catenary to Contact clearance less than 500

Figure 494 - Fixed-Anchored Pull-Off on tight track curves (high RL)

SUPPORT STRUCTURES

Masts mostly used I-beams for lightly loaded situations (e.g. *Figure 493*), and steel channels with welded spacers placed at regular intervals for the higher loads (e.g. *Figure 494*).

Some common masts were the "F" and "T" masts, with their welded battens (as seen in *Figure 494*).

ANCHORS

Simple anchors were employed for terminating and anchoring both the catenary and contact wires. Anchor guys used solid steel rod (with turnbuckle to help mast vertical alignment), and they were generally installed at 45°, down to a concrete guy block in the ground.

The termination insulators were mostly twin 250mm (10") diameter porcelain insulators installed in series, and often with a steel spacer plate in between to improve the lightning flashover performance. They were installed with their clevis directed to the live OHW (tongue to mast), to help minimise corrosion over time.

The catenary wire was commonly terminated using a *snail clamp*, and the contact wire was terminated into a *contact half-splice* fitting. However, previous varieties of these clamps may have been in use earlier on.

Special *AS Anchor Structures* were employed throughout the network to provide several advantages, especially in multi-track situations. See *Figure 495*. (Note that this situation includes a 270mm^2 auxiliary feeder for each wire run.)

Figure 495 - AS Anchor Structure at end of Overlap Bay (Chatswood c. 2002)

These AS structures were designed to be strong enough to terminate the out-of-running catenary and contact wires onto the structure, at a point above the associated track. This provided a single bay overall (not the more traditional 3-bay overlap). Unfortunately, in this situation, the catenary of the in-running wire was trapped within the portal's framework, which provided its own significant challenges.

OVERLAPS

At both ends of the single *overlap bay*, both the in-running and out-of-running catenary and contact wires were mostly supported and registered (for each track) on a portal structure.

Because the catenary and contact wires do not move longitudinally with changes in temperature, span wires could be used to support and register both sets of wires, provided suitable 1500V insulation was installed to keep the 2 different electrical sections isolated from each other.

The contact wires are *fully droppered* at their typical spacing of about 4.57m (15') throughout the overlap bay and up to the anchor locations. This was needed because the contact wire tension at hot temperatures can plummet to less than 2kN, and the contact needs to be regularly supported to keep its sag out of trouble (vertically clear of any pantograph).

Also because of the low tensions of both the catenary and contact wires when hot, catenary and contact *insulated knuckles* were used to help keep the parallel wires in the overlap bay spaced apart by about 250mm to 300mm throughout this bay. This helped prevent the wires from clashing and shorting out the 2 electrical sections, under conditions of high wind speeds and particularly with gusting winds. The number of knuckles needed was dependent on the length of the overlap bay.

The *overlap length* (where both contact wires are each riding on the pantograph in the overlap bay) was also a function of temperature. Under cold conditions the overlap length was likely to be short, but was considerably more generous under hot conditions (controlled in a big way by the amount of catenary sag).

Figure 496 shows an old overlap arrangement at Roseville (this OHW was replaced by regulated OHW in about 2005). The actual overlap bay is in the foreground, and main the portal structure handles both in-running and out-of-running wires and for both tracks.

Quite often, the out-of-running catenary and contact wires used to *cross the track to anchor*, as shown. I'm reasonably sure this was done to try to keep the OOR contact radial loads low and also acting in a direction that permits their attachment by short spans to the common cross-span wire, without fouling the nearby in-running pull-off arm attachments. The down side to this approach is the added expense of the more complicated OHW runs, when initially running it and when later maintaining it. And it's certainly against the current requirement for *independent registration* of OHW for both tracks (but of course, this is now corrected).

If you look carefully, you should be able to see a pair of contact-to-contact in-span feeders in the foreground which, in conjunction with the catenary-to-catenary feeder jumpers (near the portal suspension locations) provided the important heavy-current continuity from one wire run the next.

OOR pennant insulators were needed in the catenary and contact wires since they were crossing the opposite track when heading to anchor. This isolated portion of OHW would have had a potential jumper, installed between the OHW of opposite track and this wire, to prevent any floating section (which would otherwise have been against the standards).

Figure 496 - Fixed-Anchored OHW at an Overlap (Roseville c. 2002)

4.1.2 Blue Mountains Compound OHW System

The only *Compound* OHW system in Sydney was built in the 1950s between Penrith and Lithgow across the Blue Mountains. This area has many portions of steep and winding tracks (with continuous lengths of 1 in 60 gradient and some steeper lengths of 1 in 30). It's located amongst beautiful but rugged mountain terrain. The electrification of the existing line was officially opened in 1957.

Figure 497 - Compound OHW

Apparently steam trains were predominantly used as the prime movers prior to this electrification. And compared to the proposed electric trains, diesel-electric trains were deemed unsuitable for the long steep grades, as noted in the document "Electrification of the Sydney-Lithgow Railway Line", by R.W. Mackay et al., and published in the *Journal of the Institution of Engineers, Australia*, *Jan-Feb 1958*.

The below comparison was included in the above document, and it speaks volumes about the relative tractive capability of the electric locomotives at that time (compare power to weight):

Electric Locomotive	3,840 hp (rail)	108 tons weight
Diesel Locomotive	1,350 hp (rail)	120 tons weight
D58 Steam Locomotive	2,475 hp (rail)	228 tons weight
C38 Steam Locomotive	2,250 hp (rail)	201 tons weight

The compound OHW is a high current capacity fixed-anchored OHW system. It was probably justified here because of the heavy freight needing to be hauled at a reasonable speed over the mountains at the time, and electrification was obviously seen as a very practical solution (and one which brought with it many other benefits).

Additionally, this electrification could be advantageous to commuters, with comfortable electric trains allowing travel all the way from Central to Lithgow (and vice versa), without changing trains, and so shortening journey times. A commute from Katoomba to Sydney's

Central Station takes about 2 hours, and this was and remains a handy travel option for people living in the mountains and working in Sydney or Parramatta CBDs.

Apparently between Parramatta and Penrith (the flat area) the OHW equipment was to be suitable for 70mph (113km/h), with 2 locomotives coupled. Between Penrith and Lithgow (the mountains area) the OHW equipment was to be suitable for 50mph (80km/h), with up to 3 locomotives coupled – see *Figure 498*.

As mentioned previously, electric trains have a few significant benefits when compared to steam or diesel trains, and these benefits may be particularly relevant in the Blue Mountains area. The benefits of electric trains include:

- They are quick to accelerate (with the exceptional start-up torque of a dc motor, and because they carry less mass since there's no onboard fuel to cart around).
- They are relatively quiet.
- They do not pollute locally. This must be particularly appreciated when passing through long tunnels, with no plumes of smoke or diesel fumes to contend with.
- There's much less chance of starting a bush fire (especially compared to steam locos), which was probably a real and ongoing threat in this area.
- They can use *regenerative braking* when going down steep grades, to help slow down the massive weight of the train (whilst potentially delivering excess energy to help power other nearby electric trains, especially those travelling uphill), and also to help save on brake pad wear.

Electrification obviously seemed a good option in the 1950s.

Figure 498 - 46 Class triple header locomotive in Blue Mountains (with 4 pantographs raised)

The multitude of long and steep gradients called for a special OHW system capable of delivering the demanded heavy 1500V dc currents for long durations in this situation.

The compound OHW system was designed and built by BICC (British Insulated Callender's Cables) of England. Similar configurations exist in European countries including England and France.

CONDUCTORS

The Compound OHW system consists of 3 main wires (from highest to lowest above track):

⟶ *327mm² catenary / 179mm² auxiliary catenary / 193mm² contact.*

The conductor details are given back in *Table 7*.

The main catenary supports an auxiliary catenary below at about every 12m or so, which in turn supports the contact wire up to about every 6m.

This unusual OHW system was developed overseas, and seems to have these benefits:

- *Higher current rating*. There's more copper cross-sectional area (CSA) in the air with the 3 wires in parallel, and therefore it's better able to supply heavy current to the trains. This was especially needed for heavily laden freight trains travelling up the mountain to Mt Victoria (the apex), from either the east (Penrith) or the west (Lithgow). The combined cross-sectional area (CSA) of copper is almost 700mm². The regenerative braking capability of trains also necessitated bigger CSA to deal with the prolonged levels of heavy current being conducted, without overheating.
- *Improved pantograph current collection performance at speed* (explained later on).
- *Better voltage regulation*. This is a consequence of the greater copper CSA, which also allowed the spacing between substations and sectioning huts to be increased. Note that there are 2 sectioning huts located in between substations for this project, to help improve the voltage regulation, increase the spacing between the more expensive substations, and/or improve the important electrical protection scheme.

Figure 499 is a photo of the OHW outside Katoomba Substation. It shows how well this old OHW system blends in with the surroundings.

Figure 499 - Compound OHW outside Katoomba Substation

Figure 500 is a view of a 67m bay of compound OHW conductors. Note that the upper view *(a)* shows the bay to scale, and the lower view *(b)* shows the same bay but with its vertical scale enlarged by a factor of 10x, which is normal design practice to help magnify the situation in a vertical sense, to better understand the various parts and what's going on.

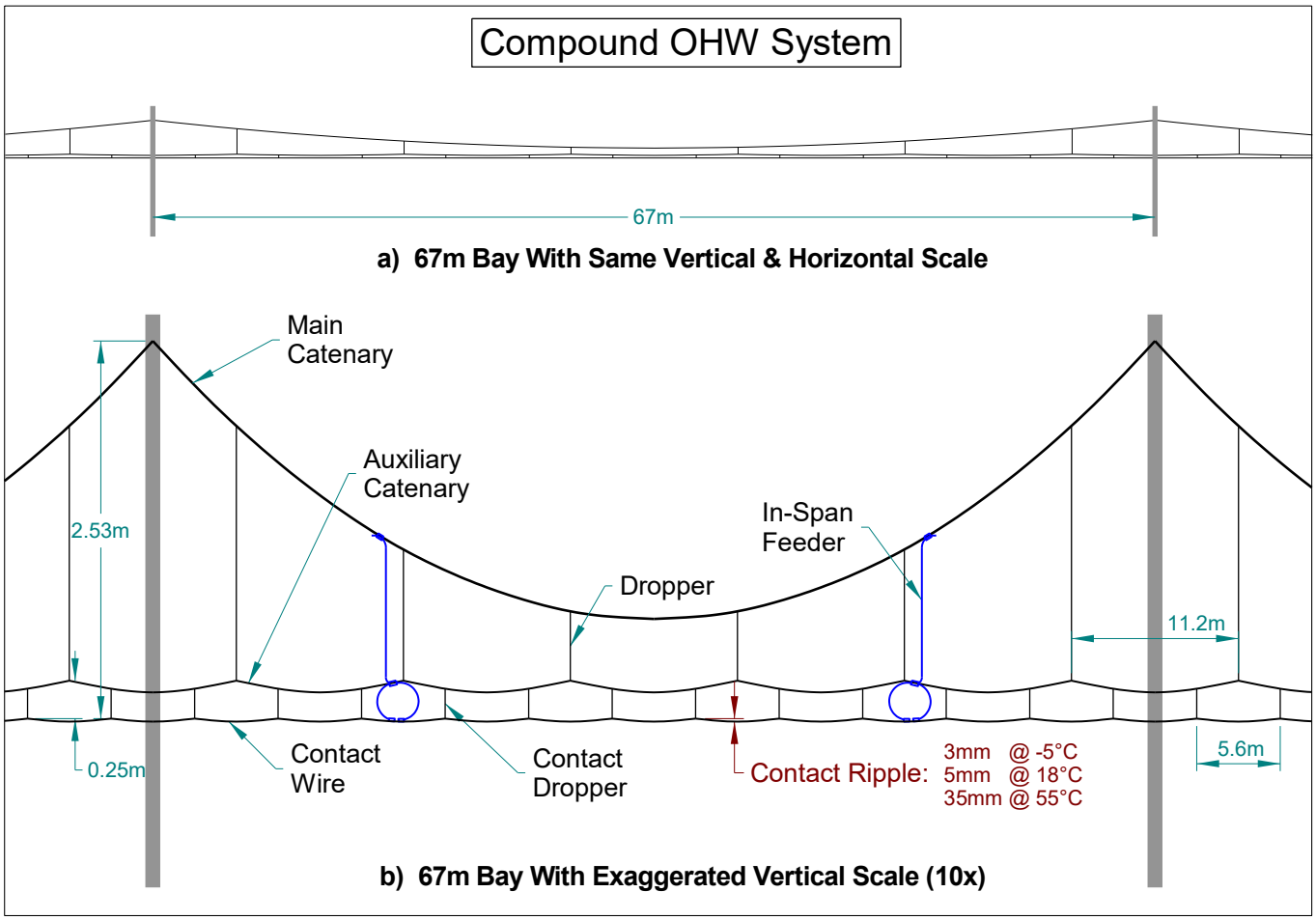


Figure 500 - A Bay of Compound OHW (lower view enlarged)

So, this system was designed for heavy current supply to trains, and as a consequence is able to cope with regenerative braking, which slows the train down by it becoming a generator. The generated power could help to supply power to any nearby trains. Any excess power that could not be used would instead result in increased voltage in the OHW. If this voltage exceeds about 2,000V at the substations or sectioning huts, then the excess energy is diverted (dumped) into special resistor banks ("bee hives") located at the substation outdoor area, and the energy is dissipated (wasted) as heat.

The main problem for the OHW with regenerative braking is that current flows during train acceleration and now also during braking (but in the opposite direction). This means the OHW conductors get hotter (current causes the wire to heat up), and if there's insufficient time for the OHW to cool down before the next train comes along, this can cause the temperature to rise in a step-wise fashion, and eventually become overheated and permanently damaged. So, it would need these trains to be spaced further apart to avoid this scenario.

The consequence of OHW that gets too hot are:

- The contact wire *sags* below its minimum height and may touch the roof of the train, causing the dc circuit breakers to trip, thus affecting train operations (delays to the timetable).
- The copper conductors can begin to *anneal* if their temperature goes over about 80°C. Annealing is the softening of the hard-drawn copper. With the various conductors under

significant mechanical tension, this can cause the conductors to permanently stretch, thus again lowering the contact wire and possibly causing it to touch the top of the train. However, this annealing is *permanent* damage to the wire, which is much more serious than the above dot point, because the amount of damage can be spread over kilometres of OHW. And it has to be repaired by renewal which is a big and costly job.

The compound system is a fixed-anchored OHW system. However, as I understand it, the contact wire profile under the hot and cold extreme temperatures behaves in a better way to that of the normal F/A simple catenary system. This is beneficial for higher speed train running, and probably provides for better current collection with heavy freight trains drawing heavy current (and heating the wires up).

It seems this contact behaviour comes about because it is supported by the auxiliary catenary, which itself is supported by the catenary. Importantly, the first and last auxiliary catenary droppers straddle the main catenary suspension points, shown as 11.2m in *Figure 500*. This results in a slightly more uniform raising and lowering of the auxiliary catenary throughout the bay under temperature changes, and thus also the supported contact wire.

Figure 501 shows the conductor profile of a few bays of compound OHW at cold (-5°C), design (18°C) and hot (55°C) temperatures. [Note that -7°C (20°F) was the minimum temperature for design work.] The 35mm contact wire ripple at 55°C occurs over about 5m or 6m (between droppers), and can normally be well tolerated by pantographs.

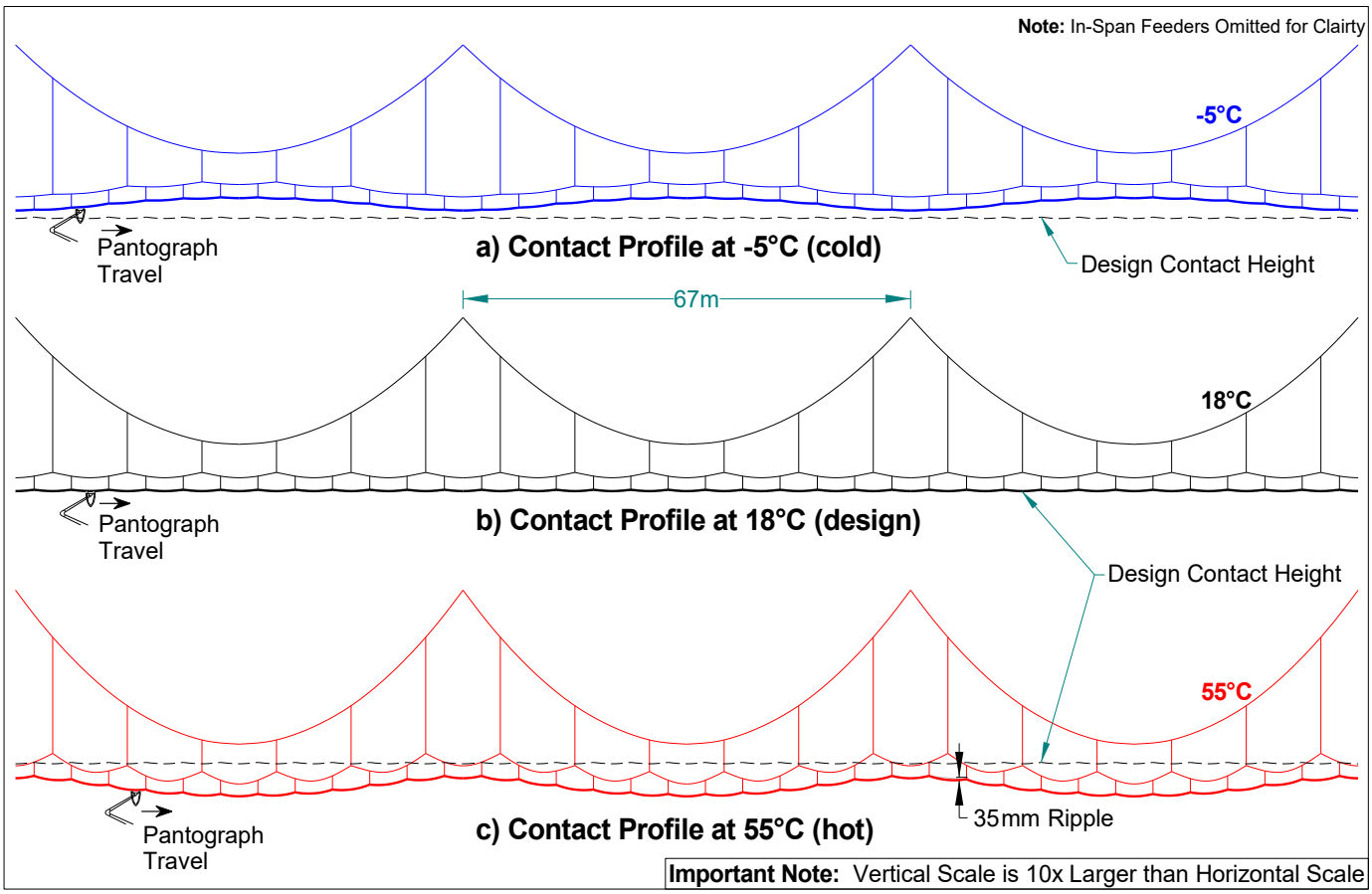


Figure 501 - Comparison of Contact Profile at temperature extremes

Fortunately, because of the higher altitude, the OHW design temperature for this steep mountainous area is 18°C (rather than the normal 21°C). So, in theory there's a benefit of 3C° that can lead to an increase of current rating for this area, which is a good outcome.

The weight of the auxiliary catenary wire supporting the contact wire below with its uniformly spaced droppers, can distort the parabolic catenary shape to a significant degree, as shown in *Figure 502*.

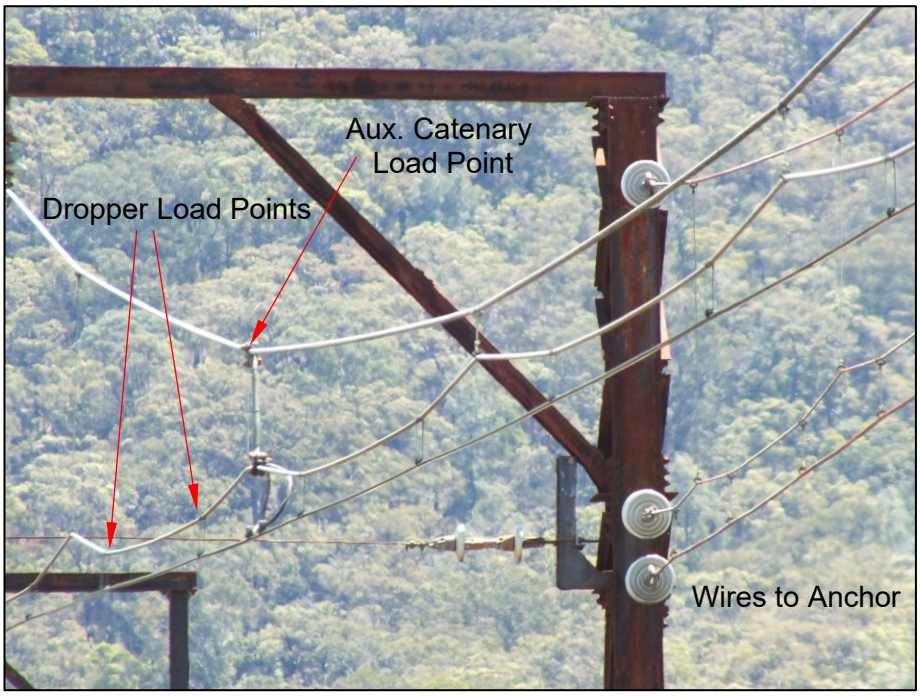


Figure 502 - Droppers distorting the parabolic Catenary shape

Droppers were an unusual arrangement, that used copper strip bent over the auxiliary catenary wire and bolted to the stainless steel contact clip. See *Figure 503*. The strip in this photo forms a "figure-8" that traps the auxiliary catenary, making it a *restricted dropper*. This helps prevent too much contact uplift occurring in hot weather with multiple closely-spaced pantographs passing through. I think they are mostly used at and near overline bridges, and adjacent to catenary support locations.

The normal dropper arrangement just has parallel sides without the figure-8 being formed. An "aeroplane sleeve" installed on the auxiliary catenary wire protects this wire from damage if the dropper moves up and down relative to the auxiliary catenary as pantographs pass through.

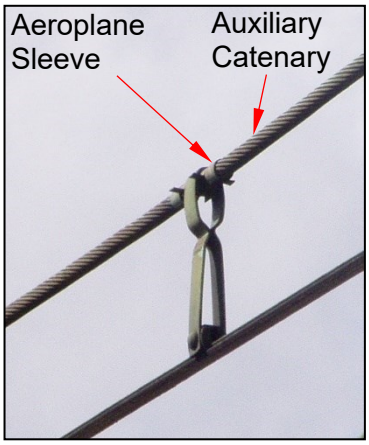


Figure 503 - Dropper from Aux Catenary

With the contact clamp, the process of tightening the stainless steel bolt and nut against the outer copper strips and against the 2 halves of the contact clip brought all these components together, and also firmly gripped the upper wedge shape in the contact wire. This approach resulted in a solid connection with no movement at that vital contact wire connecting point, and it seems to have been a real success.

Note that it was this particular contact clip that was inspiration for the later development of the "universal" contact clip, described in *Section 3.1.3.5, New Contact Clamp – Fitting 95/30.*

The virtual span for the contact wire in the Compound OHW was more like 6m (instead of the 4.57m used elsewhere). This slightly larger VS figure results in a lower band of tension change with temperature, which is a good outcome.

The Blue Mountains area is one of the few areas in the electrified network where it is possible to have significant ice accumulation on the OHW conductors. (See *Figure 599* further on for instance.) This can cause various problems:

- Ice build-up on the conductors increases the diameter of the conductor, causing additional weight and wind loading on the support structures. Also, the tensions at these cold temperatures are extremely high, resulting in higher radial loads and anchor tensions in all conductors. Both these factors can cause the OHW support structures to fail if they are in poor condition (e.g. severely rusted, or damaged by vehicles).

- Ice on the underside of the contact wire can cause pantograph connection problems to train services, especially for the first train operating in the morning.

SUPPORT & REGISTRATION

The various S&R arrangements support the catenary and they register both the auxiliary catenary and the contact wires.

Long bay lengths (often requiring use of 1, 2 or sometimes even 3 mid-bay pull-off arrangements), gave the advantage of a larger *virtual span* (VS) figure, and fortunately as a direct consequence, gives a narrower tension change with temperature extremes. However, this is at the cost of slightly taller OHW portal structures, needed to cope with the higher catenary heights that deal with the additional (deep) catenary sag, whilst also providing space for the auxiliary catenary (located between catenary and contact wires).

Some low overline bridges required the OHW designers to bring the catenary and auxiliary catenary wires to the same level as they passed under the bridge, to squeeze them into the limited space under the bridge. The contact was then supported from the main catenary. See *Figure 504* for some details of the general arrangement used.

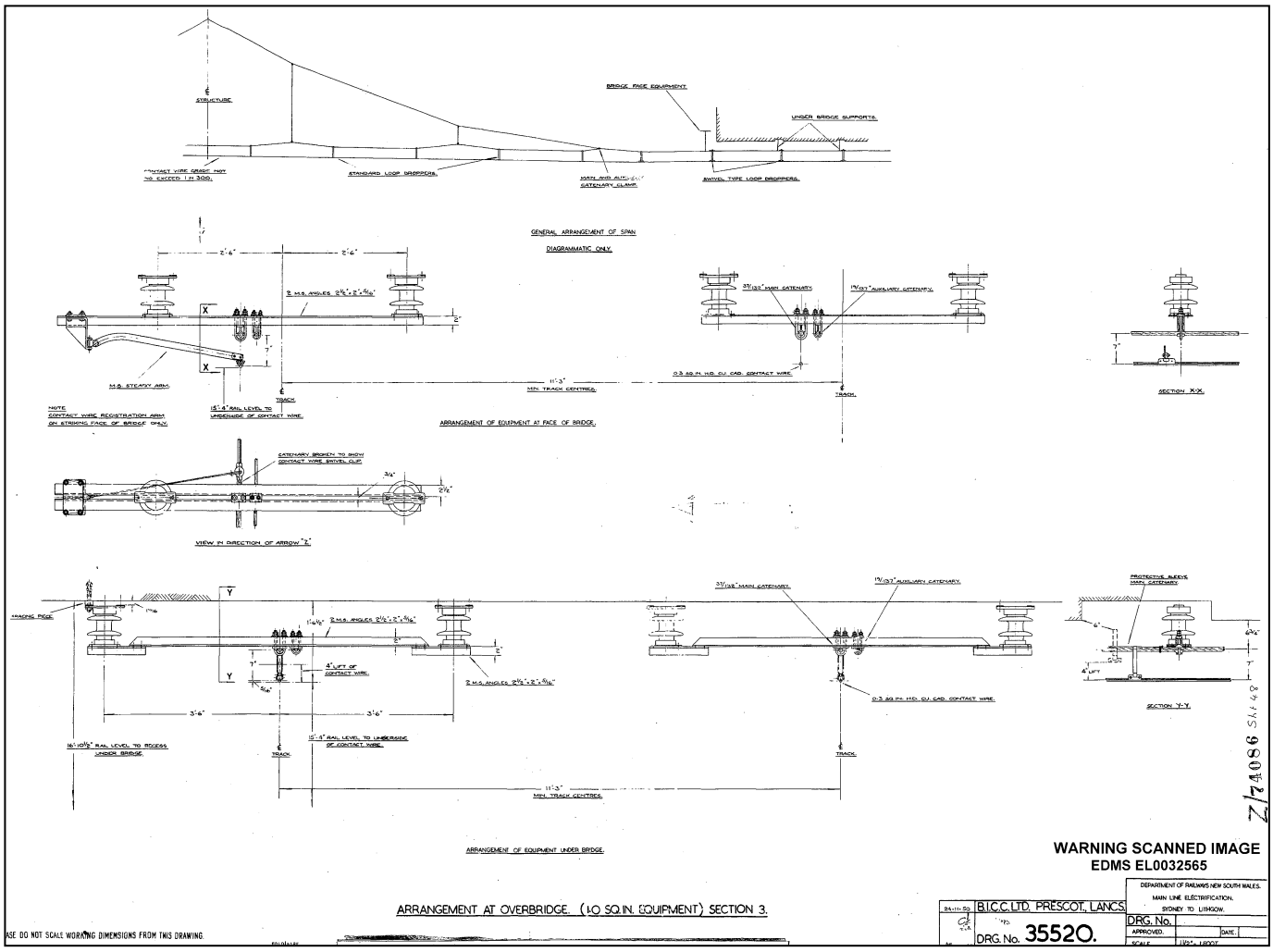


Figure 504 - Catenary and Auxiliary Catenary side-by-side under OLB

The multitude of tunnels in this area must have created nightmares for the designers and builders of the OHW. In fact, the minimum electrical clearances in some tight tunnels had to be reduced from the normal 150mm down to only 100mm (4").

Clearances were so tight that they resorted to using fibreglass rod insulators to help hold the radial loads of the contact and auxiliary catenary wires in some circumstances. (This was possibly the first use of fibreglass in Sydney's OHW system.) *Figure 505* shows an unusual support & registration arrangement in one of the tunnel situations.

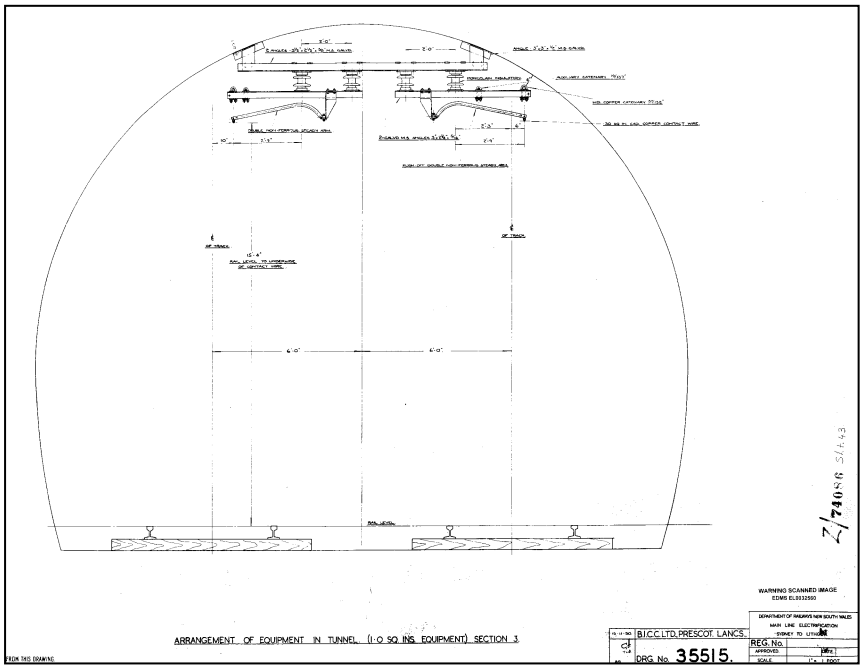


Figure 505 - Unusual Tunnel S&R arrangement

According to the "Electrification of the Sydney-Lithgow Railway Line" document, to reduce major maintenance within the tunnels, monel metal bolts were used wherever grouted bolts were necessary.

There are a number of fittings unique to the compound OHW system, and spares had to be kept in case of failures. (Note that some areas in the mountains have recently been upgraded to new regulated OHW, so spares from the old system should be available from this work.)

As mentioned, the catenary is supported on structures located up to about 73m apart, and this may require 1, 2 or even 3 intermediate pull-offs, especially when on curved track, as shown in *Figure 506*. (This particular situation has 2 pull-offs in the bay for each track.)

Figure 506 - Tight track curve requiring 2 intermediate Pull-Off's between Portals

The auxiliary catenary is supported from the catenary above by auxiliary droppers that have an average spacing of 12.2m (40ft) – the actual distance varies depending on the bay length.

Figure 507 - Elaborate Cross-Span Pull-Off

The drive for *independent registration* in the 1990s led to the multitude of cross-spans being progressively removed and replaced by drop verticals installed between tracks, to register the OHW for the remote track/s. (This was part of the *Metropolitan Track Strengthening Project*, where OHW adjustments were needed as wooden sleepers were replaced by new thicker concrete sleepers.) *Figure 507* demonstrates one such complex 2-track span arrangement that's crying out for independence.

For this work, a special design was approved for the Compound OHW system that used readily available and relatively lightweight stainless steel hardware, as used in yachting.

Figure 508 shows one such altered span arrangement from a DV.

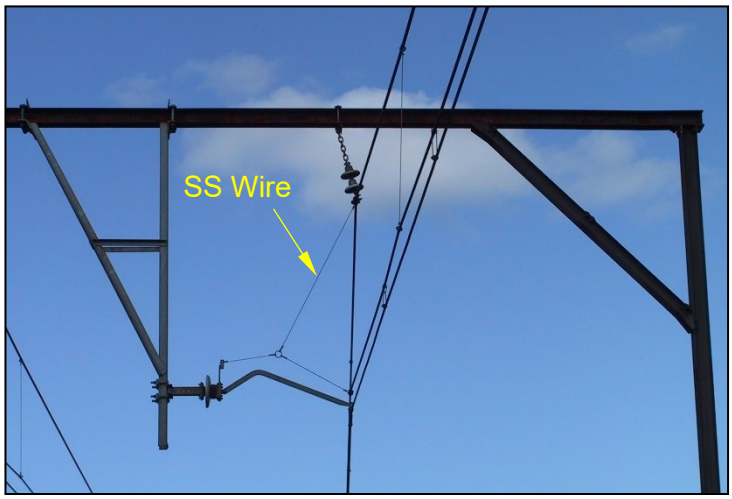


Figure 508 - SS span fittings for wire registration

This situation included multi-strand SS wire along with SS rings, thimbles and swages – in certain approved applications only. The decision for using this high-strength SS wire was probably based on reducing the cost of conversion, compared to the cost of using the usual 90mm² copper span arrangement (as shown in *Figure 506*), given the huge population of equipment needing it.

Here, the auxiliary catenary wire is registered by a thin 4mm diameter SS wire, from a catenary pull-off raiser bracket installed on the live side of the post type insulator. A ring was installed midway and supported from the catenary, in order to lift the SS wire well clear of the crank in the pull-off arm to avoid rubbing. The radial load in the auxiliary catenary wire was deemed sufficiently low for using the SS wire (which has incredible tensile strength for its size).

But the important point here is that the use of these rather lightweight SS fittings was *conditional on there being no dc current passing through them*. Evidently in the past, some stainless steel fittings that were under tension had become brittle over time because they passed small levels of dc current, and they eventually failed.

So, for this reason, both the pull-off gunmetal clamps – one installed on the main catenary wire and one installed on the auxiliary catenary wire – needed to use a thick neoprene rubber sleeve installed onto the wire to isolate it from its surrounding gunmetal clamp. In this way, no current should find a path through the stainless steel wire.

It is important that this neoprene insulation undergo periodic testing to confirm it's still doing its job.

Note that approval for the use of stainless steel wire was also given for the guy wires of the Type 6 Section Insulator, which are mainly needed for aligning the SI. (Some of these SIs are also installed in the Compound OHW system in the Blue Mountains.)

More information is given back in *Section 3.2.6.4, Compound OHW*.

SUPPORT STRUCTURES

I think most OHW structures were of I-beam construction.

Others structures used welded fabrication construction (maybe due to the absence of readily available steel in the quantity required back in the 1950s, or because of BICC's preference back then, or maybe due to their strength?). Unfortunately, having multiple welded sections can make inspection of corrosion and subsequent repairs difficult in some circumstances.

However, the structures in the mountains have performed relatively well in terms of corrosion over the years, no doubt helped by the remoteness from the coastal sea water and other corrosive pollutants. (After all, people go to the mountains for the fresh air, don't they?)

ANCHORS

Special portal structures with A-frame legs were often used to anchor the 3 sets of OHW conductors on each leg, as depicted in *Figure 509*.

Figure 509 - Anchoring OHW on A-Frame Legs

This approach obviated the need for anchor guy wires and associated concrete anchor block. But this required portal legs and their concrete foundations to cope with the enormous wire loads, especially in winter time (and the loads were terminated at heights of 5m to 8m above track level).

In these cases, the pull-off cross-span needed a special bracket to allow connection near the contact and auxiliary catenary anchor attachments, as seen in *Figure 509*.

OVERLAPS

The various design standard drawings show a parallel horizontal spacing of the 2 sets of wires within the overlap bay set at 380mm (15") apart.

Overlaps are similar to other fixed-anchored ones, except that the additional auxiliary catenary wire had to be included in the arrangement.

At the middle of long bays, they used a special "contact wire porcelain insulated distance fitting", to help keep the parallel wires separated under strong winds during hot temperatures. This used an 85mm diameter porcelain insulator that was raised above the in-running contact level and with contact clamps at each end (instead of the permali beam arrangement used elsewhere in Sydney's system for similar situations). A very similar "catenary wire porcelain insulated distance fitting" device was also used at mid-bay to tie the 2 catenary wires together with about 250mm spacing, to make them behave also.

SECTION INSULATORS

Because of the need to terminate the 3rd wire – the auxiliary catenary – this system needed its own type of section insulator, which was provided by BICC.

The Type 6 SI has been adapted to replace the BICC arrangement in more recent years.

Refer to *Section 3.6.3, BICC (Compound) Section Insulator* for more information.

SWITCH ARRANGEMENTS

It seems that special switches were used for the compound OHW system, as detailed in *Section 3.7.2, BICC Switch*.

FEEDING ARRANGEMENTS

Feeding to the OHW required attachment of the aerial feeder wire to the catenary wire, then on to the auxiliary catenary wire and then to contact wire using the typical in-span feeder arrangement for this system. Refer to *Figure 445* further back for an example of the aerial feed from a substation to the OHW.

This seems to be one of the few areas where it was permissible to connect the aerial feeder wires directly to the tensioned OHW conductors without the use of a feeder loop (which is no longer acceptable practice). But this would have required at least 2 sets of parallel feeder clamps onto extremely clean wires in order to prevent the connection from burning (heating up) and annealing.

Figure 510 - View of Aerial Feeder connections to Compound OHW conductors

Refer to *Figure 510* for a view of typical connections from aerial feeder wires to catenary and auxiliary catenary, with normal in-span feeder connection to contact wire at 2 locations. (Portal structure is on the left, supporting the OHW conductors.)

Also it is no longer acceptable to run bare aerial feeders across one track to the opposite track, as explained in *Section 3.8.0.4, Types of Feed*.

Aside:

I understand that this BICC project introduced the 193mm² Contact wire size to Sydney, probably as a means of better controlling pantograph uplift (with additional contact weight) and getting more copper in the air (for better current and voltage regulation, etc.). In order to deal with the extremely high tensions at the sub-zero temperatures experienced in the Blue Mountains, the contact wire metal chosen was cadmium–copper.

Collective experience over the subsequent decades has ultimately deemed that the 193mm² contact wire size in cad-copper was probably a mistake. This is mainly due to the extreme difficulty in totally removing any kinks in the contact wire, to end up with a perfectly flat wire when the pantographs pass through. (This was discussed previously in *Section 3.1.2.5, A Contact Wire with a Problem*.)

4.1.3 City Underground Tunnels

The City Underground tunnels are mostly single track tunnels, of classic "breadloaf" shape and built since the 1920s. See *Figure 511* as an example, but it's almost impossible to see the OHW.

Interspersed between the lengths of tunnels are the various stations, which either have ceilings of horizontal beam construction supporting horizontal concrete slabs (e.g. Wynyard and Town Hall Stations) or broad arch construction (Museum Station).

These tunnels were initially designed for single-deck trains, so when double-deck trains arrived much later on in the 1960s and became the standard consist, it must have posed some real problems when trying to squeeze in the taller train size in certain areas. Where the track could be lowered to deliver more vertical space, it was arranged. But I understand there are a few areas where this could not be achieved.

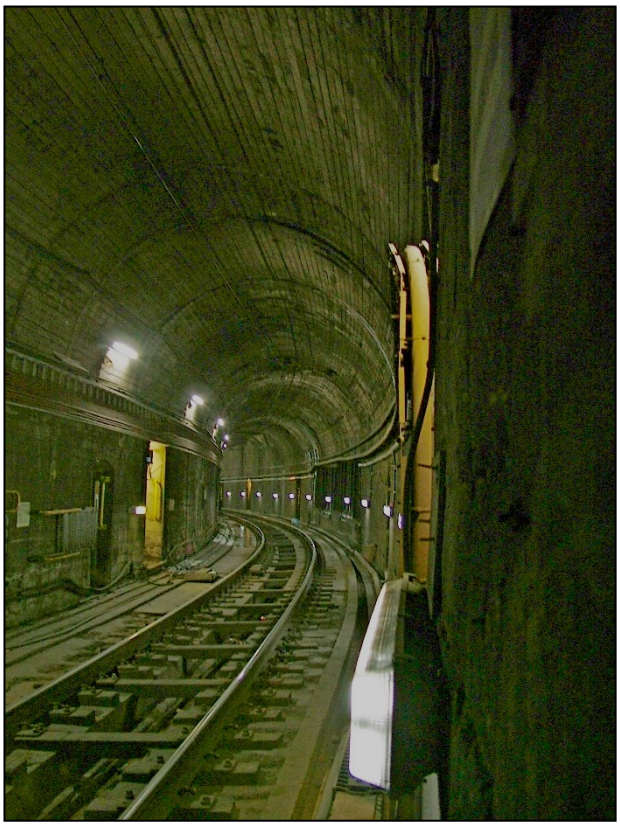


Figure 511 - Down Shore Tunnel near Town Hall

In terms of the OHW, the problem was (and remains) mainly the mid-bay contact height under hot conditions (slack tension). Indeed, the normal absolute minimum contact height of 4.57m at 55°C for any fixed-anchored OHW system, had to be somewhat relaxed here because it was impossible to meet this requirement in all areas of the City Underground tunnels. So, the standard was reduced to 4.42m at 45°C *for this area of the network only*. (This is stipulated in the current standards.) This meant that the wire could be as close as 100mm above the train, but the slower train speeds here generally lessen the amount of vehicle bounce (the upward movement further encroaches this electrical clearance). But there needs to be a few things going wrong at the same time for the OHW to touch the train roof and stop trains – in this case, any significant vehicle bounce also needs to happen on a really hot day. (Note that 1500 volts will flash over at about 1mm clearance, and less that this if the air is moist.)

Over the past almost 100 years that this system has been operating, apart from the occasional "low wire" problem under extremely hot conditions, the system has been operating reasonably well. This level of reliability is probably due to the simplicity of this fixed-anchored OHW system. But it's important to emphasise that it needs to be properly designed in the first place, and if operational changes (or other) are made during its life, they need to be properly assessed (e.g. perform a load flow study to determine any upgrade requirements) and appropriate changes made (e.g. add auxiliary feeders in vulnerable areas). Also, even small physical adjustments to the OHW need to be made with great care, strictly following the requirements of the associated design change. In particular, the catenary tension must be maintained to its standard value at 21°C and not become under-tensioned (unless a design check is performed).

Given the age of the infrastructure, most of the OHW remains in reasonable condition. This is helped by the fact that it's in a restricted area and located inside a tunnel rather than outside in the open (which would otherwise face all sorts of environmental and other problems, including wind storms, lightning, vandalism damage, etc.).

The old anchor bolts for attaching OHW brackets to the concrete ceiling in certain areas, were installed using "lead wool" embedded in the ceiling. These anchor bolts remain in good condition to this day with very little corrosion (unless they happen to be located where water seeps through the tunnel lining, which is not very common).

Unfortunately, it is an area that sees a lot of dust accumulation, which is caused by all sorts of things but especially by brake dust from trains. Because there is no cleansing rainfall, periodically this pollution needs to be physically removed from the surfaces of the vital 1500V insulators, so as to minimise any leakage currents causing other reliability problems.

Fixed-anchored OHW remains valid for tunnels even today, due mainly to its simplicity and cost effectiveness – provided it's been properly designed, built, operated and maintained.

CONDUCTORS

I understand that the early city underground OHW initially comprised the 137mm² contact size, and with either the 165mm² or 270mm² catenary wire supporting it.

Many areas later upgraded to the larger 193mm² size to get more copper in the air. In addition to the obvious increase in current carrying capacity and lower resistance, this heavier contact wire was also expected to better counteract the upward pantograph force and reduce the amount of uplift in the restricted space above.

The contact wires were made from cadmium-copper to withstand the tension extremes under cold conditions (due to the contact wire's extremely short virtual span).

The conductor details are given back in *Table 7*.

Over the many decades, various areas have added 270mm² auxiliary feeders next to the main OHW, to help boost the current rating and to reduce circuit resistance for higher DCCB settings as train loads grew.

In order to minimise contact wire wear (particularly to the side of the contact wire), any crossover wiring necessitated the use of a "flat knuckled" contact arrangement. This is where the main line and crossover contact wires are configured to be at the same level in the vicinity of the various pantograph forking-in points. This sometimes led to some interesting (complicated) contact wire paths from anchor to anchor.

SUPPORT & REGISTRATION

Inside the tunnel curved roof areas, a single post type insulator was mostly installed from the tunnel lining for supporting the catenary wire, and another post type insulator was used to register the contact wire from the side of tunnel using a suitable length pull-off arm. The catenary was positioned directly above the staggered contact wire. Space was limited, and a single post type insulator (with 156mm space between its connecting flanges) could usually fit in these tight situations. Even so, sometimes small pockets needed to be cut into the tunnel lining for mounting the pull-off insulator, to get the required clearances from the heel of the pull-off arm to the edge of passing pantographs.

In areas with a flat ceiling, which usually occurred at underground stations, there was sufficient additional space to install a pair of suspension insulators to support the catenary wire (the insulator string length is about 450mm from ceiling attachment point to catenary wire). This approach also happened in cases of large arch-shaped tunnels such as those at Museum Station, demonstrated in *Figure 266* further back.

Figure 512 shows the use of twin suspension insulators to support the catenary wire, in an area that had more vertical space to accommodate it.

On curved track, pull-off arrangements were needed to align the contact wire so that it sweeps across the pantograph through both adjacent bays.

On straight track, the contact wire still needed to sweep across the pantograph to reduce wear at its centre portion. But this sweep could happen by staggering over a much longer distance, such as staggering at every second catenary support location. In this case there was no need for a pull-off at every support location, since there is no significant side wind to cause blowout problems. This saved money. This approach of minimising the number of pull-off locations was especially useful at stations, because each instance required a drop vertical to be installed from ceiling, or cross span from the wall, so as to attach the insulator and arm to get the contact wire into the required position (the less of these pull-offs, the better/cheaper).

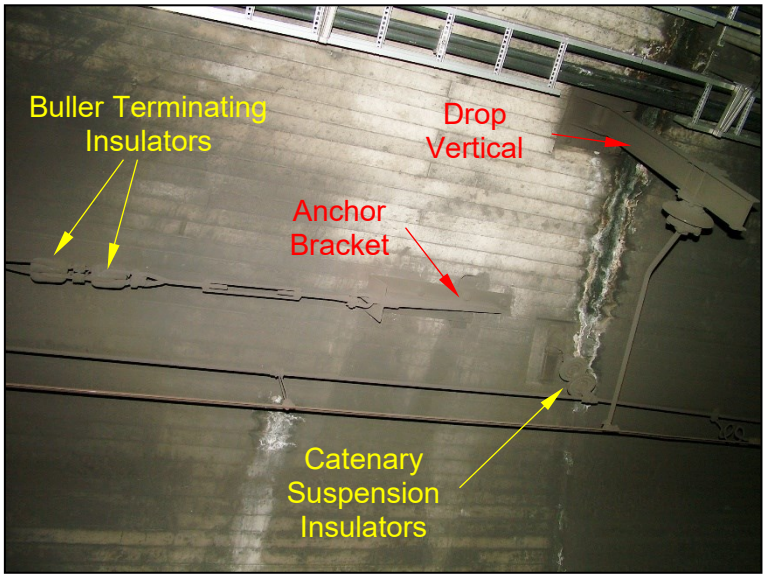


Figure 512 - Upward view of supported, registered & anchored OHW (Wynyard Tunnel)

At each catenary support location, the catenary wire was located directly above the staggered contact wire position. When the catenary was supported by a standard post type insulator, to achieve some lateral adjustability of the catenary position, a steel plate 400mm or so long and made from 90mm × 10mm (or 12mm) steel flat section, was installed into, or bolted onto, the ceiling at an appropriate location. The old-style standard post type insulator (fitting 452) has a steel flange at each end, with 4 holes spaced 108mm apart (on a 152mm pitch circle diameter). These post type insulators can be mounted to the underside of this plate using a pair of special shallow U-bolt fittings, with 108mm spaced legs. These straddle the plate from above, and insert into the hole pairs in the insulator. In this way the insulator can slide along the plate to suit the required stagger position at that location, then tightened with the four M12 nuts on the U-bolts. This provided a sound mechanical connection of insulator to ceiling.

More information is given back in *Section 3.2.6.4, City Circle*.

SUPPORT STRUCTURES

Various steel brackets are installed into the tunnel lining to attach the OHW at their correct location to suit the OHW conductors. Brackets were in the form of steel angles, I-beams, "T" sections (possibly cut down the neutral axis of an I-beam), bent steel flats, etc.

As mentioned previously, there are many instances where *lead wool* was inserted into holes drilled into the tunnel lining, to help solidly anchor the steel bolts for fastening the attachment plate. This approach seemed to last the test of time.

Drop verticals were used in areas that had more available space. See *Figure 512*.

ANCHORS

Simple anchors on the tunnel ceiling were conveniently located above the track. The sequence of anchors for an overlap (in the direction of travel) is usually:

Contact anchor, then *catenary anchor* (both for the next tension length), then the *overlap bay*, then
catenary anchor then *contact anchor* (for previous tension length).

The contact anchors were located furthest away from the overlap bay because they needed greater longitudinal distance in order to rise up to the high anchor point (from in-running height at the overlap bay, up to their anchor attachment plate). This required the calculation of the worst-case contact sag (i.e. tightest tension, at coldest temperatures), because otherwise this might limit the effectiveness of the overlap. This approach is used for overlaps in almost all tunnels that use tensioned OHW conductors.

The actual *anchor height* relative to track is normally a function of the curvature of the tunnel lining and the contact stagger (relative to the superelevated centreline of track). This 3-dimensional nature can make the design of the OHW particularly tricky and time-consuming. Flat ceilings are a lot simpler to deal with in this regard.

Anchors sometimes employed twin loop strain insulators in series to terminate the runs of OHW, as shown in *Figure 512*. This was probably standard practice way back in time, and probably quite acceptable in the absence of rain, but is no longer acceptable for new works. The superior approach is to use the standard twin porcelain termination insulators (or newer *K-Line* insulators).

OVERLAPS

The catenary and contact anchors are usually installed directly above where the in-running conductors need to be, in order to get the correct stagger alignment in the overlap bay.

Fortunately, there's normally no need to consider wind loading and blowout for these overlaps, making pantograph security easier to achieve in the overlap bay.

4.1.4 Eastern Suburbs Railway Tunnels

A standard 270mm² catenary and 2x137mm² contact fixed-anchored OHW system was first developed and used for the (then new) Eastern Suburbs Railway (ESR) Tunnels in the mid 1970s. Since then, the standard fixed-anchored OHW system for subsequent tunnels was this same OHW System No. 28:

270mm² catenary / 2 x 137mm² contacts (although the tensions may differ slightly).

I think this decision to standardise on twin contacts was primarily made in order to provide additional contact weight, to more effectively counteract the upward pantograph force at low (hot) conductor tensions, so as to limit the amount of contact uplift in the confined space of a tunnel. But it also provided a large continuous current rating, as well as lower resistance for improved electrical protection (or to be able to space the substations slightly further apart).

In the ESR, fixed-anchored OHW was used throughout the various tunnels, but a regulated version of this OHW (System No. 5, described in *Section 4.2.3*) was installed on all viaducts located outside the various tunnels.

The overall success of this F/A system was encouraging, and it was probably as a result of its simplicity, low cost and reliability. Because of its good reputation, it was later used for the Airport Line Tunnel (which opened in 2000), and then the Epping to Chatswood Tunnels (which opened in 2009).

As far as I am aware, in the standards this OHW system remains a current option for wiring inside future tunnels (and for good reason).

CONDUCTORS

The conductor details are given back in *Table 7*.

The contact wire was made from cadmium-copper, chosen for its high strength (which is needed in a fixed-anchored system under cold conditions).

Delrin bar droppers were developed for this project – the dropper arrangement supported the twin contacts from the single catenary. This spaced the contact wires 50mm apart – refer to *Section 3.1.3.4*, *Twin Contact Droppers*.

The clever design of this dropper arrangement allowed the contact wires to automatically adjust their individual heights to a small degree, in sympathy with the oncoming pantograph (this is even if pantographs have highly worn carbon strips). This meant that both contact wires were forced to slide along the pantograph and evenly share its upward pressure. The end result is more uniform wear on both contact wires over time. (This is unlike other independent twin droppers, which are spaced 1m longitudinally apart and which unfortunately don't provide even contact wire wear.) The rotation of the bottom end of the dropper is also a benefit on highly superelevated track, because the carbon strips of a pantograph are parallel to the track and this dropper can force both contact wires to balance and share the uplift force.

Thee plastic "Delrin" bar itself prevents any current from feeding between catenary and contacts, and also between both contact wires, which is another significant benefit of using this type of dropper.

SUPPORT & REGISTRATION

The development of light gauge pull-off arms for each contact wire was done to reduce the downward force and minimise any chance of disruptive arcing as fast pantographs pass through.

More information is given back in *Section 3.2.6.4, Eastern Suburbs Railway*.

SUPPORT STRUCTURES

Nothing unusual about the OHW support from tunnels here.

ANCHORS

Fixed anchors were employed inside the tunnels. These simple anchors were similar to that used in the City Circle and elsewhere.

4.1.5 Airport Line Tunnel

The Airport Tunnel OHW was designed starting 1997 and the fitout project was mostly completed in 1999, ready for the Sydney Olympics in 2000. The tunnel project back then was part of the "New Southern Railway" (NSR), linking Central Station with Turrella and establishing the Domestic and International Airport Stations (adding 5 stations in total).

Most of the route is in a large tunnel that houses the twin tracks. See *Figure 513*. There are several different shaped tunnels throughout the route, with a number of slightly different "breadloaf" shaped tunnels in the hard rock area from the Central end to beyond Green Square Station, whence it became the standard "Tunnel Boring Machine" (TBM) circular shape for most of the remaining route, and finally with flat ceiling "Cut & Cover" shape near the Turrella end of the tunnel.

Figure 513 - Airport Tunnel OHW being commissioned (1999)

The fundamental requirement for the success of this OHW system was that it be designed to take into account the large variations in conductor temperature (although not as large as outside in the open). Being relatively insulated from the outside, the tunnel *cold* temperature was somewhat fixed (10°C), whereas the *hot* temperature needed to be properly modelled, based on the maximum ambient temperature, train current draw characteristics (especially accelerating current), train speeds, track grades, etc.

Initially there were no crossovers in this project, however towards the end, one was requested to be installed between Central and Green Square inside the tunnel. It was a leading crossover, making the design and operation of its OHW simpler.

CONDUCTORS

Because of the success of the previous Eastern Suburbs Railway OHW system, the same OHW conductor system was chosen for this project – OHW System 28:
270mm² catenary / 2 x 137mm² contacts.

However, the contact wire metal was to be tin-copper.

The conductor details are given back in *Table 7*.

SUPPORT & REGISTRATION

A common key requirement in the Airport Tunnel fitout contract was that there be a minimum amount of equipment installed for the various services, and this included the OHW system.

This requirement was met through the use of a temperature profile of the OHW conductors that was modelled throughout the tunnel, based on the proposed 270mm² catenary and 2x137mm² tin-copper contact fixed-anchored system. The modelling was provided by a sophisticated in-house program called "E-train" (by Greg Hunter). This took into account the OHW conductors, the location and characteristics of proposed substations and sectioning huts, the tracks (traction current return paths) and their gradient, the load characteristics of the various trains and the timetabling of services to achieve the initial 8 trains per hour (and also, I think, some diversification applied to the timetable). It was later changed to 12 trains per hour (travelling in each direction) and designed and built as such.

Based on the modelled maximum temperature profile of catenary throughout the tunnel for each track, the spacings between the OHW supports (the bay lengths) were maximised, and this resulted in the minimum amount of support & registration equipment needed.

Even though the information further on in *Figure 517* appears rather small, it shows the resulting *Tension Length Diagram*, including the *maximum catenary temperatures* (in 5C° increments) expected throughout the Airport Tunnel. The included table shows how long the *bay lengths* can be as a function of maximum catenary temperatures in the tunnel. Where the maximum temperature was cool (about midway between substations and sectioning huts), the bay lengths could stretch out to 40m, but where the catenary became hot (near the substations), the bay lengths reduced down to only about 21m or even as low as 17m where the catenary went to 60°C. Note also the additional lengths of auxiliary feeders, installed to lower the catenary temperature, which could then increase the bay lengths to advantage.

Figure 514 - Wolli Ck Station – Down Track (right) has 5 Conductors

The planned placement of 270mm² auxiliary feeders, installed about 150mm to the side of the catenary, took place starting at substations and radiating out for hundreds of metres, to get the catenary temperature down and achieve savings elsewhere. Wolli Creek Station (*Figure 514*) was a particularly nasty spot for temperature rise, since it was located well below ground level but was exposed to direct sunlight, with almost no cooling cross winds to help lower the OHW temperatures. It was like an oven, and this required *2 auxiliary feeders* in the Down direction (due to a significant uphill start from the station heading towards Turrella). This small length of track may have the most copper cross-sectional area in the OHW anywhere in the entire electrified network – with 3x270mm² catenary wires and 2x137mm² contact wires all in parallel (= 1,084mm² copper CSA), for a few hundred metres! Wolli Ck Station is shown as Arncliffe North in *Figure 515*.

Because of the *roller coaster* nature of the vertical track profile through parts of the tunnel (*Figure 515*), and the need to not breach the minimum contact height of 4.57m (under worst conditions), it became necessary to adjust the normal flat contact profile at 25°C (the standard

temperature), to instead *hog* this wire in the bays where the track reached an apex (e.g. on the Sydney-end of Green Square Station). This hogging was achieved by shortening the droppers towards mid-bay throughout the affected bays, as calculated by the dropper computer program developed for this project. In this way, the contact wire at 25°C was more parallel to the track through its peak.

For this project several new support & registration standard arrangement drawings were developed, to suit the different tunnel shapes, station areas, open areas (Wolli Creek Station), and other unusual situations.

In a similar approach to the Mark-2 cantilevers, each unique standard arrangement was given a prescriptive coding that gave much information about the type of arrangement to be used, staggering, need for pull-offs, etc.

Code Example: "**+4JOLK/L**".

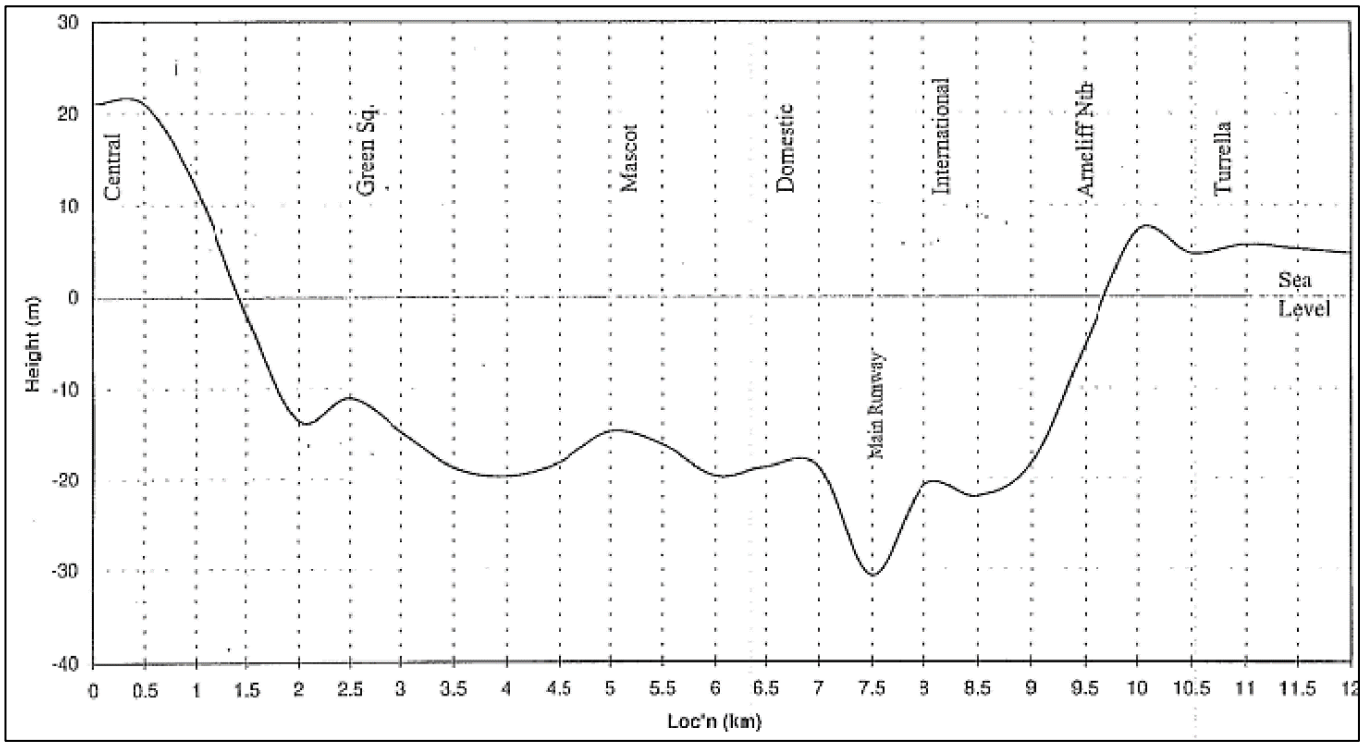


Figure 515 - Airport Line track profile (Central to Turrella)

A computer program called "T-Calc" was developed to take the coding as input for each support & registration location, along with tunnel location and track specifics, in order to detail all construction information needed for each support & registration arrangement, for each wire run. This included all dropper and in-span details within each bay.

Post type insulators for catenary support were installed on an almost horizontal steel plate, which had multiple holes for selecting an appropriate catenary lateral stagger position for each location. See *Figure 516* as an example, which shows a locked main catenary (left) and auxiliary feeder mounted on a common insulator.

The need for using multiple holes came about because of the pattern of 4 *threaded inserts* of the (then new) resin post type insulators that were standardised for future use in Sydney's OHW system. It was felt that the normal practice of using a pair of backing plates and set screws to "clamp" the insulator onto a 90mm wide steel support plate, did not offer enough frictional grip – plastic on steel – in situations of high catenary radial load. Using discrete holes on a wider plate offered the necessary insulator security and reliability.

There are 10 hole pairs on each plate – these holes were accurately drilled, or punched out and linished, to provide a flat surface underneath for mounting the insulator. (Note that the insulator's threaded inserts do not tolerate holes that are out of alignment, so it was crucial to specify tight tolerances of ±0.5mm for all these holes – not just the pattern of 108mm hole spacing, but also the 152mm PCD – for all 20 holes.) This approach worked well.

In *Figure 516*, note the survey cross-hair mark with a "1" on the concrete tunnel lining. This mark was used to locate the steel bracket accurately to the desired position according to the design for that location. (There were up to 4 such marks at each location – for support brackets and for registration brackets, and for Up and for Down tracks.) The mark's Eastings, Northings and Relative Level (3-dimensions) were fed back to the design process into a computer program to accurately calculate the resulting catenary height, which could then also yield accurate dropper lengths for each adjacent OHW bay. The calculations also took into account any rotation of the mounting plate from its ideal horizontal position due to the tunnel curvature there (see the cross-sections in *Figure 519* for what this means). Hole selection for achieving the correct stagger was also calculated by the program.

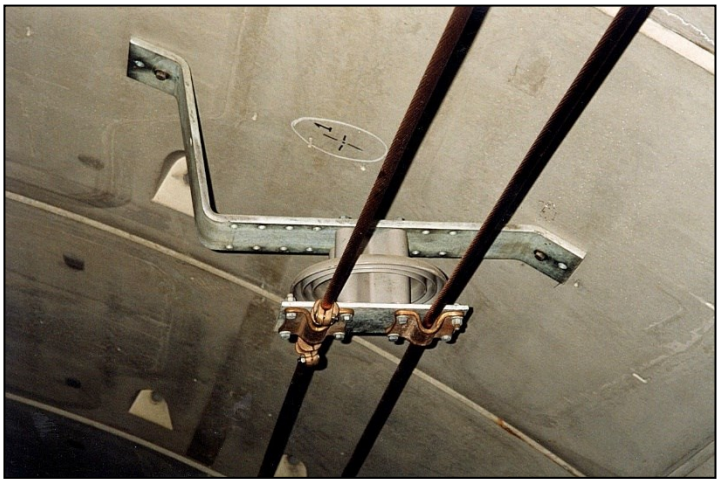


Figure 516 - Post Type Insulator attachment using multiple holes

More information is given back in *Section 3.2.6.4, Airport Line*.

SUPPORT STRUCTURES

Support brackets were attached to the tunnel lining using chemical (epoxy) anchors, as specified in the contract. See *Figure 519* for instances of typical S&R arrangements.

ANCHORS

The approach and equipment for terminating the OHW conductors were typical of those used elsewhere throughout the OHW network. Again, see *Figure 519* for some instances of anchor brackets.

OVERLAPS

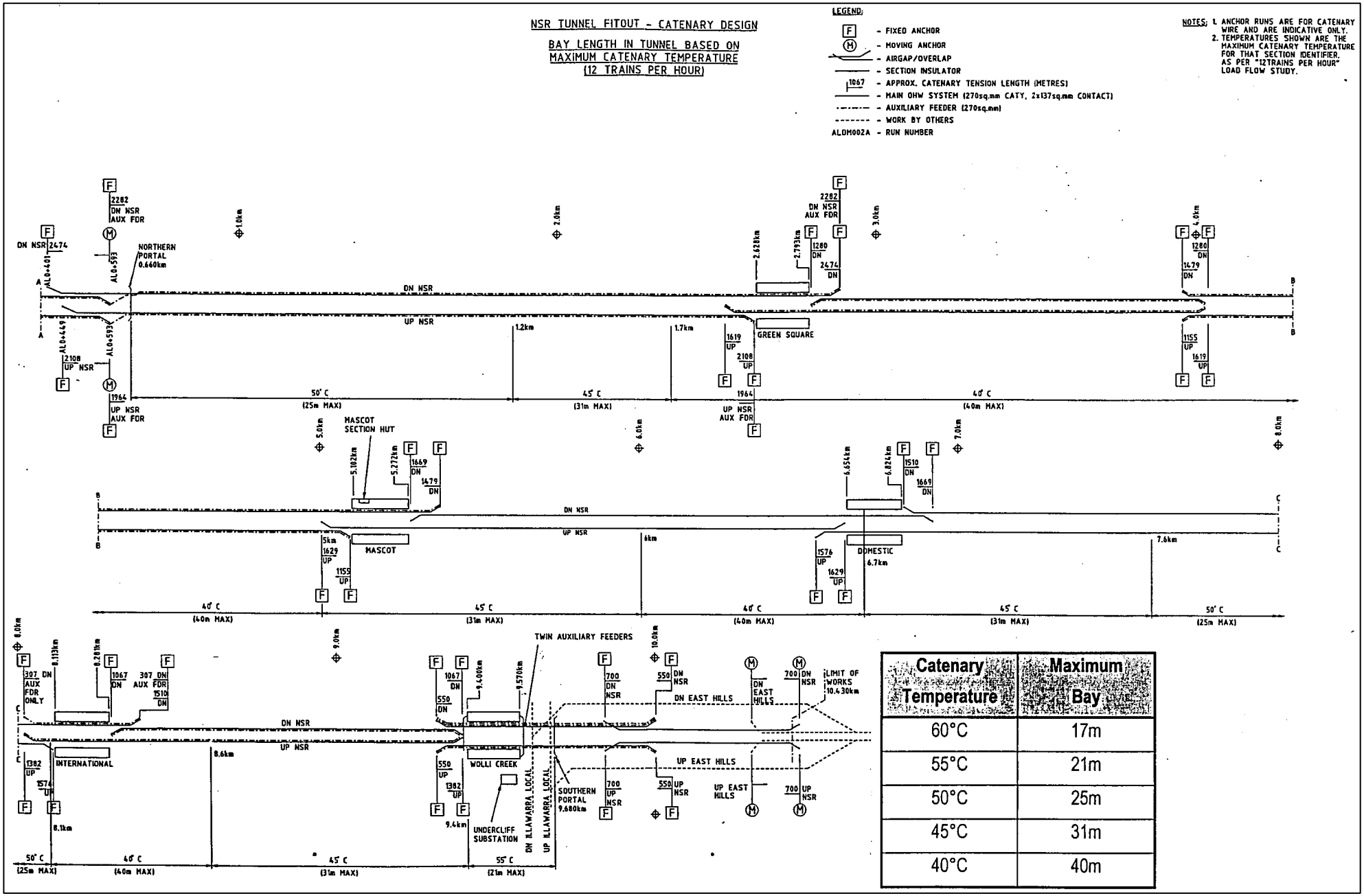
The 12 overlaps needed inside the tunnel were particularly time-consuming to design, which is typical of any tunnel situation. This tunnel has more height space above trains due to the space needed to fit 2 train tracks side-by-side. The higher ceiling heights, particularly in the dominant TBM portion, meant that the contact wires had to rise by a greater amount from in-running to reach their anchor points.

The catenary support heights and anchor heights were all a function of their attachment position on the tunnel lining, and this was dictated by the staggered contact wire position (which was most important), with the catenary attachment and anchors being vertically aligned with the twin contact wires.

To make matters more difficult, the catenary support brackets and anchor brackets were designed for a particular spatial position a few hundred millimetres from the tunnel lining, but unfortunately the curved lining rotated their attached positions, and this had to be calculated

and taken into account in each instance – see *Figure 519* for the type of bracket rotation referred to here. A separate purpose-designed computer program was developed to help accurately predict the catenary & anchor heights as a function of the lateral (stagger) offset from track centre and the tunnel profile (there were several tunnel shapes on the route). The accuracy and convenience of this program helped enormously in the design process.

To help understand the nature of the problem, I have included parts of the 2 design drawings of one such overlap in this tunnel. Refer to *Figure 518* which shows the 2 overlapping conductor run profiles in an elevation view, and the conductor staggering in the plan view. The corresponding cross-section views are given in *Figure 519*, which were intended to help understand the 3-dimensional restrictive relationship with wires and tunnel lining. These views became an invaluable aid, both for the designers and later for the constructors.


NSR TUNNEL FITOUT - CATENARY DESIGN
BAY LENGTH IN TUNNEL BASED ON MAXIMUM CATENARY TEMPERATURE (12 TRAINS PER HOUR)
LEGEND:
F - FIXED ANCHOR
M - MOVING ANCHOR
AIRGAP/OVERLAP
SECTION INSULATOR
1067 - APPROX. CATENARY TENSION LENGTH (METRES)
MAIN OHW SYSTEM (270sq.mm CATY, 2x137sq.mm CONTACT)
AUXILIARY FEEDER (270sq.mm)
WORK BY OTHERS
ALDM002A - RUN NUMBER
NOTES: 1. ANCHOR RUNS ARE FOR CATENARY WIRE AND ARE INDICATIVE ONLY.
2. TEMPERATURES SHOWN ARE THE MAXIMUM CATENARY TEMPERATURE FOR THAT SECTION IDENTIFIER, AS PER "12TRAINS PER HOUR" LOAD FLOW STUDY.
NORTHERN PORTAL 0.660km
GREEN SQUARE
MASCOT SECTION HUT
MASCOT
DOMESTIC 6.7km
TWIN AUXILIARY FEEDERS
INTERNATIONAL
WOLLI CREEK
UNDERCLIFF SUBSTATION
SOUTHERN PORTAL 9.680km
DN EAST HILLS
UP EAST HILLS
LIMIT OF WORKS 10.430km
DN NSR
UP NSR
DN ILLAWARRA LOCAL
UP ILLAWARRA LOCAL
50° C (25m MAX)
40° C (40m MAX)
45° C (31m MAX)
55° C (21m MAX)

Catenary Temperature	Maximum Bay
60°C	17m
55°C	21m
50°C	25m
45°C	31m
40°C	40m

Figure 517 - Catenary temperature profile & maximum Bay Lengths inside Airport Tunnel

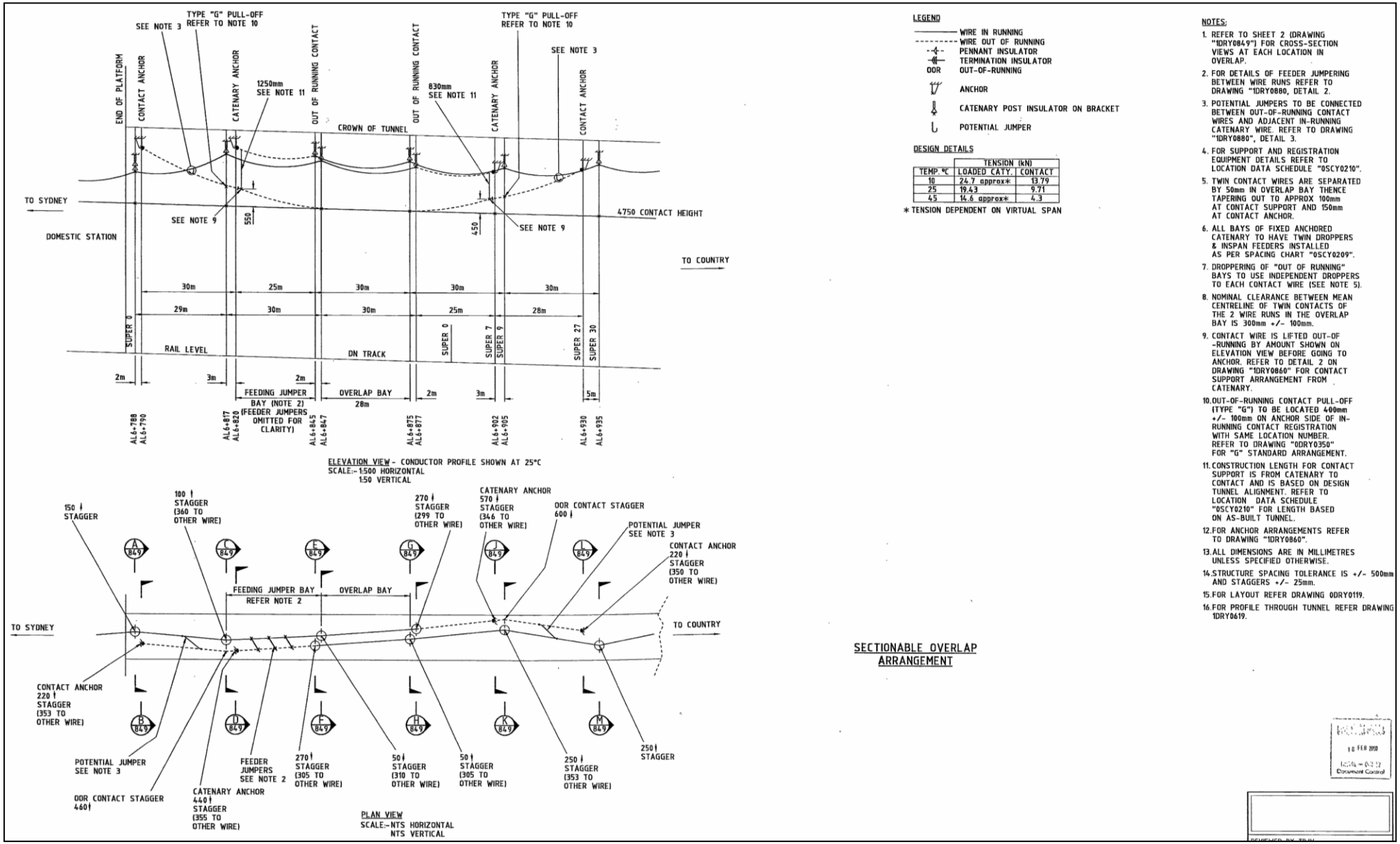

TYPE "G" PULL-OFF REFER TO NOTE 10
SEE NOTE 3
END OF PLATFORM
CONTACT ANCHOR
CATENARY ANCHOR
1250mm SEE NOTE 11
OUT OF RUNNING CONTACT
CROWN OF TUNNEL
830mm SEE NOTE 11
TO SYDNEY
DOMESTIC STATION
SEE NOTE 9
4750 CONTACT HEIGHT
TO COUNTRY
30m 25m 30m 30m 30m
29m 30m 30m 25m 28m
SUPER 0
RAIL LEVEL
DN TRACK
SUPER 7
SUPER 9
SUPER 27
SUPER 30
2m 3m 2m 2m 3m 5m
FEEDING JUMPER BAY (NOTE 2) (FEEDER JUMPERS OMITTED FOR CLARITY)
OVERLAP BAY 28m
AL6+788 AL6+790
AL6+817 AL6+820
AL6+845 AL6+847
AL6+875 AL6+877
AL6+902 AL6+905
AL6+930 AL6+935
ELEVATION VIEW - CONDUCTOR PROFILE SHOWN AT 25°C
SCALE:- 1:500 HORIZONTAL
1:50 VERTICAL
150 STAGGER
100 STAGGER (360 TO OTHER WIRE)
270 STAGGER (299 TO OTHER WIRE)
CATENARY ANCHOR 570 STAGGER (346 TO OTHER WIRE)
OOR CONTACT STAGGER 600
POTENTIAL JUMPER SEE NOTE 3
CONTACT ANCHOR 220 STAGGER (350 TO OTHER WIRE)
FEEDING JUMPER BAY REFER NOTE 2
OVERLAP BAY
CONTACT ANCHOR 220 STAGGER (353 TO OTHER WIRE)
POTENTIAL JUMPER SEE NOTE 3
OOR CONTACT STAGGER 460
CATENARY ANCHOR 440 STAGGER (355 TO OTHER WIRE)
FEEDER JUMPERS SEE NOTE 2
270 STAGGER (305 TO OTHER WIRE)
50 STAGGER (310 TO OTHER WIRE)
50 STAGGER (305 TO OTHER WIRE)
250 STAGGER (353 TO OTHER WIRE)
250 STAGGER
PLAN VIEW
SCALE:- NTS HORIZONTAL
NTS VERTICAL
LEGEND
WIRE IN RUNNING
WIRE OUT OF RUNNING
PENNANT INSULATOR
TERMINATION INSULATOR
OOR OUT-OF-RUNNING
ANCHOR
CATENARY POST INSULATOR ON BRACKET
POTENTIAL JUMPER
DESIGN DETAILS
TENSION (kN)
TEMP. °C | LOADED CATY. | CONTACT
10 | 24.7 approx* | 13.79
25 | 19.43 | 9.71
45 | 14.6 approx* | 4.3
* TENSION DEPENDENT ON VIRTUAL SPAN
SECTIONABLE OVERLAP ARRANGEMENT
NOTES:
1. REFER TO SHEET 2 (DRAWING "1DRY0849") FOR CROSS-SECTION VIEWS AT EACH LOCATION IN OVERLAP.
2. FOR DETAILS OF FEEDER JUMPERING BETWEEN WIRE RUNS REFER TO DRAWING "1DRY0880, DETAIL 2.
3. POTENTIAL JUMPERS TO BE CONNECTED BETWEEN OUT-OF-RUNNING CONTACT WIRES AND ADJACENT IN-RUNNING CATENARY WIRE. REFER TO DRAWING "1DRY0880", DETAIL 3.
4. FOR SUPPORT AND REGISTRATION EQUIPMENT DETAILS REFER TO LOCATION DATA SCHEDULE "0SCY0210".
5. TWIN CONTACT WIRES ARE SEPARATED BY 50mm IN OVERLAP BAY THENCE TAPERING OUT TO APPROX 100mm AT CONTACT SUPPORT AND 150mm AT CONTACT ANCHOR.
6. ALL BAYS OF FIXED ANCHORED CATENARY TO HAVE TWIN DROPPERS & INSPAN FEEDERS INSTALLED AS PER SPACING CHART "0SCY0209".
7. DROPPERING OF "OUT OF RUNNING" BAYS TO USE INDEPENDENT DROPPERS TO EACH CONTACT WIRE (SEE NOTE 5).
8. NOMINAL CLEARANCE BETWEEN MEAN CENTRELINE OF TWIN CONTACTS OF THE 2 WIRE RUNS IN THE OVERLAP BAY IS 300mm +/- 100mm.
9. CONTACT WIRE IS LIFTED OUT-OF-RUNNING BY AMOUNT SHOWN ON ELEVATION VIEW BEFORE GOING TO ANCHOR. REFER TO DETAIL 2 ON DRAWING "1DRY0860" FOR CONTACT SUPPORT ARRANGEMENT FROM CATENARY.
10. OUT-OF-RUNNING CONTACT PULL-OFF (TYPE "G") TO BE LOCATED 400mm +/- 100mm ON ANCHOR SIDE OF IN-RUNNING CONTACT REGISTRATION WITH SAME LOCATION NUMBER. REFER TO DRAWING "0DRY0350" FOR "G" STANDARD ARRANGEMENT.
11. CONSTRUCTION LENGTH FOR CONTACT SUPPORT IS FROM CATENARY TO CONTACT AND IS BASED ON DESIGN TUNNEL ALIGNMENT. REFER TO LOCATION DATA SCHEDULE "0SCY0210" FOR LENGTH BASED ON AS-BUILT TUNNEL.
12. FOR ANCHOR ARRANGEMENTS REFER TO DRAWING "1DRY0860".
13. ALL DIMENSIONS ARE IN MILLIMETRES UNLESS SPECIFIED OTHERWISE.
14. STRUCTURE SPACING TOLERANCE IS +/- 500mm AND STAGGERS +/- 25mm.
15. FOR LAYOUT REFER DRAWING 0DRY0119.
16. FOR PROFILE THROUGH TUNNEL REFER DRAWING 1DRY0619.

Figure 518 - Typical Overlap in Airport Tunnel – Elevation & Plan views (sheet 1 of 2)

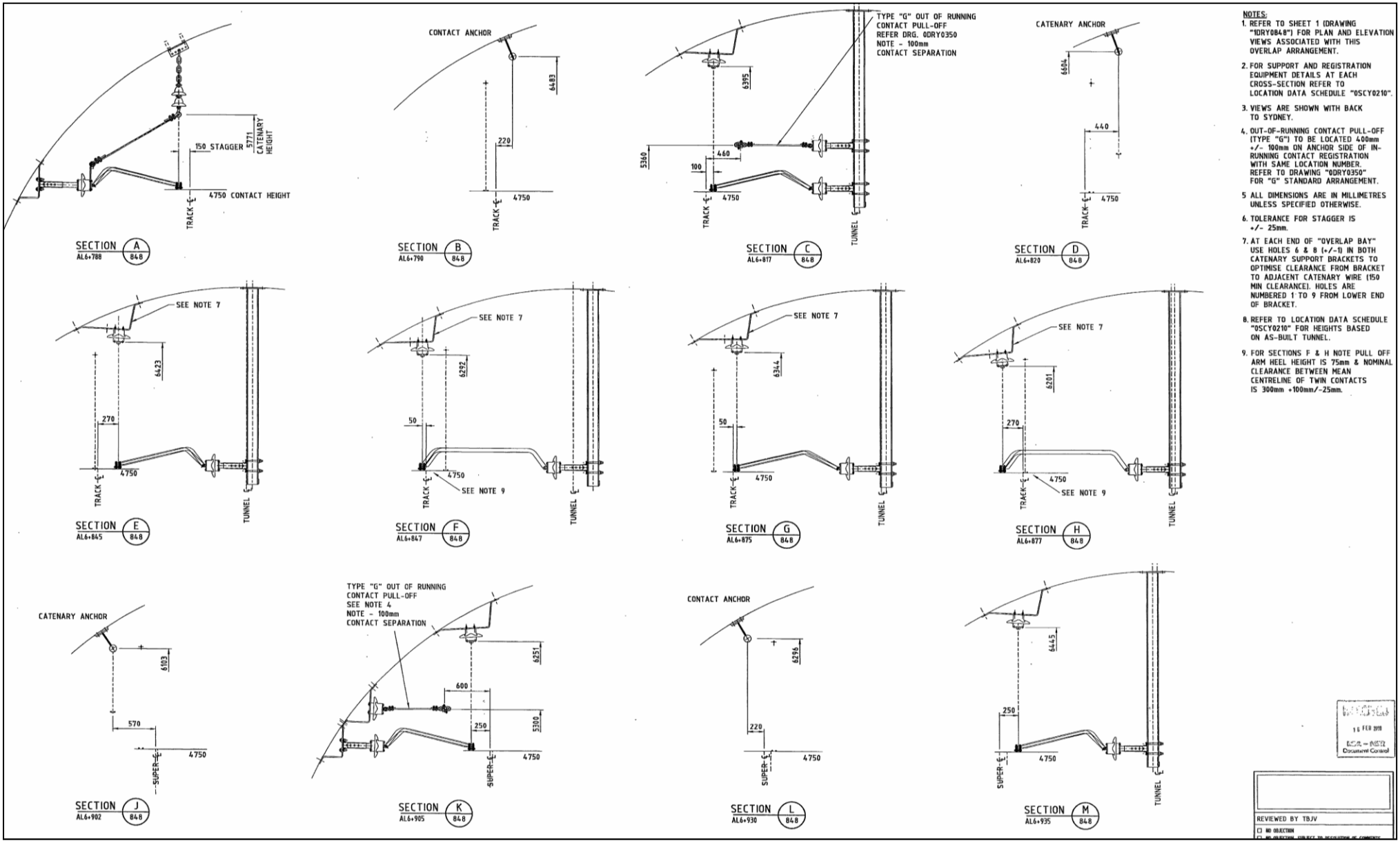


Figure 519 - Typical Overlap in Airport Tunnel – Cross-section views (sheet 2 of 2)

4.1.6 Epping to Chatswood Tunnel

This train route was constructed mostly in twin bored track tunnels, and the line was opened in 2009. (I understand that the idea of a large tunnel housing both tracks, as was done for the Airport Line, was deemed unacceptable for any future tunnel projects due to certain fire/emergency egress aspects.)

CONDUCTORS

Like the Airport Line OHW, this project also adopted the same OHW conductor configuration as Eastern Suburbs Railway, employing System 28:

single 270mm² catenary with 2x137mm² (tin-copper) contact wires.

Also, like the Airport Line, the OHW design took advantage of an increased design temperature of 25°C.

The conductor details are given back in *Table 7*.

Aside:

It's probably worthwhile to suggest that any future fixed-anchored tunnel OHW should consider the thermal benefits of closely matching the contact and catenary sizes. So, a fixed-anchored OHW system with twin 165mm² catenaries and twin 137mm² contacts would likely be an optimum system for this environment (although it's not a standard OHW system at the moment).

Such a system would provide a relatively large amount of "copper in the air" (604mm²) to help reduce circuit resistance (to allow high DCCB settings and/or increased substation spacing), and be able to provide a large continuous current rating for powering today's power-hungry trains. Importantly, this system would provide for optimal cooling down before the next train comes along to heat it up again, thus reducing the likelihood of annealing the OHW (all 4 conductors cool at roughly the same rate). If needed in certain areas, additional 165mm² (or 270mm²) auxiliary feeders could be independently-supported to the side to supplement the system.

It would likely be a highly efficient and effective OHW system for tunnels.

SUPPORT & REGISTRATION

Arrangements were essentially similar to that used for the Airport Line.

More information is given back in *Section 3.2.6.4, Epping to Chatswood Line*.

SUPPORT STRUCTURES

Similar to Airport Line.

ANCHORS

Similar to Airport Line.

OVERLAPS

Similar to Airport Line. Refer to *Figure 520*.

Figure 520 - Epping to Chatswood Tunnel OHW (Overlap) being commissioned

Figure 521 - OHW View of Overlap wires from work train

4.1.7 Steel Catenary in Yards

The steel catenary / copper contact OHW system has mostly been installed in some sidings and yards, where slower speeds and a consequently lower current rating was acceptable for supplying the (mostly freight) trains.

Various programs had been established over recent decades to try to remove all steel catenary from Sydney's OHW network, mostly because of the increased risk of failure (e.g. rusting) of the ageing system. But I think there still remains some steel catenary in smaller areas of the network, e.g. at Penrith Yard in 2014.

CONDUCTORS

The catenary is typically a small wire (91mm²) supporting a standard 193mm² or 137mm² cad-copper contact wire using regularly spaced droppers with typical dropper spacing (about 4.57mm).

Refer to *Figure 522* which compares a rusted (brown) steel catenary located next to an oxidised (green) copper catenary. The catenary saddle clamp installed on the steel catenary for the dropper should ideally have some form of insulation installed between catenary and the clamp body (e.g. neoprene rubber) to prevent dc current flowing into and along the catenary. Note the abandoned "half-moon & shell" dropper clips installed on both catenaries in this photo. Also, the copper catenary has a "restricted" dropper (possible due to the higher track speeds) while the steel catenary has a "short" dropper arrangement.

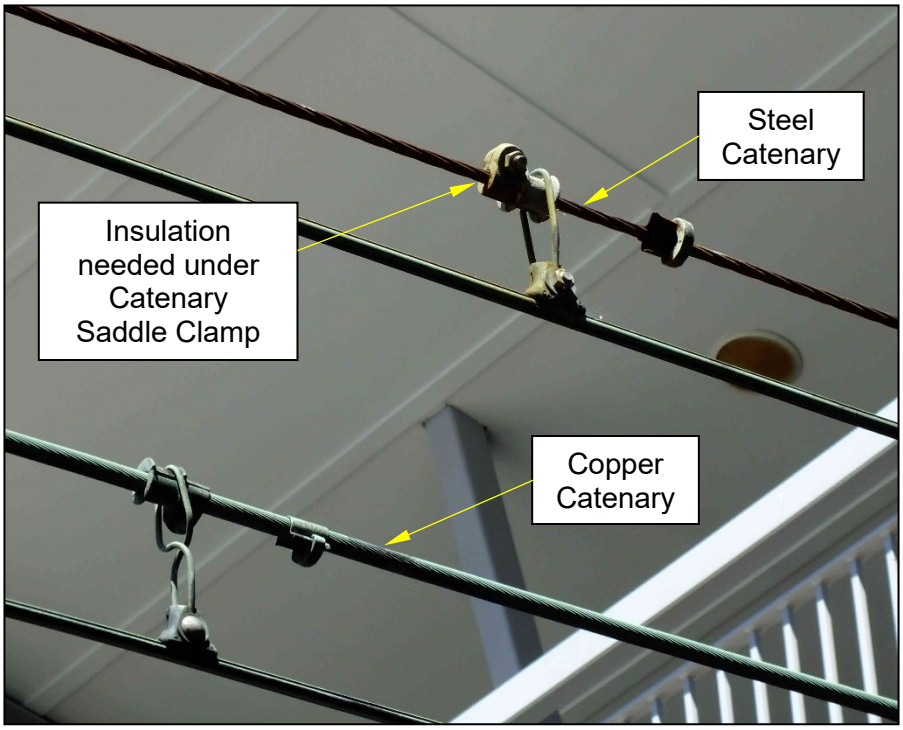


Figure 522 - Steel versus copper Catenary

The steel wire typically comprises 7 strands of 4mm diameter hard steel wire, with each strand zinc coated to help prevent corrosion (rusting). It is extremely stiff and is difficult to cut.

I am guessing that steel was chosen because, compared with an alternative contact-only system (described in the next section), the steel catenary could better control the contact wire sag under hot temperature conditions and so achieve longer bay lengths, for a more economical outcome.

Steel is also considerably cheaper than copper.

Additionally, the temperature/tension response of the steel catenary is better than that of the copper equivalent, yielding less tension change with temperature (both hot and cold).

However, there can be big problems if people don't treat this system with proper care.

It is not desirable for the steel catenary to pass any dc current, and so the catenary wire is insulated from the contact wire at each dropper and support location. This is because:

- Steel has a much higher electrical resistivity. Typically, 91mm² steel has a resistance of 2.1 Ω/km compared with 0.2 Ω/km for equivalent copper.
- It is difficult to reliably achieve a good electrical feeding connection from copper to steel. (A high resistance joint here could overheat and damage the OHW when passing reasonably heavy current.)
- There's an increased risk of corrosion setting in when passing even small current, particularly at any clamp attachments and within the strands of the conductor (where moisture can reside for long periods). It is a significant hidden failure mode.

Wire runs using steel catenary are no longer constructed in Sydney.

SUPPORT & REGISTRATION

Mostly these runs were held up using normal portal suspension arrangements as per the normal fixed-anchored copper catenary OHW.

Pull-offs from stand-alone masts helped set staggers around curves so as to extend bay lengths and control blowout, thus keeping the catenary virtual span reasonably large (which is good).

SUPPORT STRUCTURES

Mostly these steel catenary runs were supported on portal structures that may be common to other normal OHW runs.

Masts were commonly used at pull-offs locations, with cross-spans to help control one or more sets of wire, particularly around track curves.

ANCHORS

Normal anchor arrangements to ground typically applied.

Terminating the steel wire for anchoring was achieved in a number of ways, including bending the wire back on itself around a suitable thimble, then clipping it with several U-bolt clamps as shown in *Figure 523*.

Figure 523 - Terminating steel Catenary

OVERLAPS

Being used mostly in yards and sidings of limited length, this system rarely had the need for overlaps.

Instead, the connection between wire runs would take place at the multitude of turnouts.

4.1.8 Contact-Only OHW

As the name implies, this system consists of the contact wire only, with no supporting catenary wire.

Provided the system has been designed correctly for the anticipated extremes of temperature, it is quite an effective system. However, it is only suitable for slow speed running and with limited ability to supply power to trains due to the minimal copper cross-sectional area available. It also needs a decent supply (substation or sectioning hut) to be located nearby, to help keep the supply voltage healthy.

This system is only ever used in stabling yards, such as the terminating Country Platforms at Central Station. There were and are other examples scattered throughout the system.

Time has proven this system to be quite effective (under the limited circumstances above) and, due to its simplicity, it is quite a reliable system. This simplicity, with the absence of a catenary wire and droppers, made it less obtrusive in an already complex yard layout, which is another positive aspect to its use.

Figure 524 is an old photo showing an 86 class electric freight train under contact-only OHW at Central.

Figure 524 - Old 86 class electric freight train under Contact-Only OHW

Note:

Given the importance of Sydney Yard to the network, it is highly likely that this system will soon be replaced with a much healthier *catenary system*, able to supply heavier current and ultimately improving reliability in what is now an old system.

CONDUCTORS

Because there's no catenary support and therefore no droppers, the contact wire itself needs to be supported at relatively frequent intervals, typically 20 to 30m apart (not the normal 4.57m or so when droppered from a catenary).

Also, the contact height should be installed higher than normal to allow the contact wire to sag at mid-bay under hot temperatures, and still remain well above the roof of a train, i.e. greater than 4.57m absolute minimum height.

If the contact was supported by a catenary, at cold temperatures the contact wire would rise at mid-bay (i.e. "hog") because the catenary wire rises and brings the contact with it. Conversely, at hot temperatures the mid-bay contact height reduces ("bellies"). Hence for a normal OHW system with catenary wire, the excursion in mid-bay contact height between hot and cold conditions can be relatively large.

However, with contact only, there can be no contact *hogging* at cold temperatures, only a reduced sag as the wire becomes bar tight. This helps reduce the overall mid-bay contact height excursion, which train pantographs need to be tolerant of (albeit at low speed).

Another benefit is the narrower (improved) tension response to temperature extremes. This is because of the larger virtual span (VS) of the contact-only system (typically 30m compared to the normal 4.57m when supported by a catenary wire). Refer to *Table 45* below. This effect can also be appreciated graphically further back in *Figure 56*.

OHW System	Contact Virtual Span	Contact Wire Tension		
		@ 0°C	@ 21°C	@ 55°C
270mm² Catenary / 193mm² Contact	4.57m	21.4kN (8.1kN higher = +61%)	13.3kN	1.9kN (11.4kN lower = -86%)
193mm² Contact-Only	30m	20.6kN (7.3kN higher = +55%)	13.3kN	5.9kN (7.4kN lower = -56%)

Table 45 - Contact wire tension variation – Normal versus Contact-Only OHW

So, the temperature/tension response is improved, especially at the hot temperature. At 55°C a normal contact wire tension would reduce down to below 2kN, whereas the contact-only wire reduces down to a much tighter figure of almost 6kN. This can in turn help reduce the mid-bay sag of the contact-only system, but this tension improvement is much needed since it is supported at 30m spacing (not supported more regularly at 4.57m.) It's all a bit of a compromise, but seems to work OK for slow speed traffic.

The sag in this 30m bay would be about 320mm at 55°C and 90mm at 0°C, giving a total mid-bay height change of about 230mm only, which is not a lot, considering such a reasonable length of bay.

SUPPORT & REGISTRATION

Refer to *Figure 525* and *Figure 240* (further back) for a typical support for contact-only OHW on straight track, from a portal structure.

This is a relatively simple arrangement, with special castings made to clamp the contact wire groove and keep well clear of passing pantographs to prevent them snagging the clamp. Links can provide contact height adjustment, and twin suspension insulators allow it to be reliably operated at 1500V.

A cross-span on the live side could help position the contact wire and control lateral movement with wind (to a degree), as shown in *Figure 524*.

On curved track or where the wire needed staggering, a pull-off arm from the side would register it and take the necessary radial & wind loads.

Figure 525 - Typical Contact-Only Support arrangement

SUPPORT STRUCTURES

Due to the absence of a catenary wire, the portal structures only needed to be about 6m high from track level.

ANCHORS

Anchor arrangements employed the typical contact anchoring arrangement used elsewhere at the time for catenary/contact OHW anchoring.

OVERLAPS

With the usual multitude of turnouts in close proximity in yards with complex trackwork, there was usually no need for any overlap arrangements.

Instead, wire runs could terminate near a turnout where the wire from another track could take its place. Ideally in a turnout, both wires would be at the same height – a flat knuckle arrangement – before one of the wires would either go elsewhere to wire another track or go to anchor.

4.2 REGULATED OHW SYSTEMS

4.2.0 General

Introducing regulated OHW to Sydney's system was, no doubt, done to bring about its many advantages over the existing fixed-anchored systems at the time. Of particular note was its ability to tolerate hot weather – no more "low contact wire" situations (which used to bring the train system to a halt so often on extremely hot occasions).

All regulated OHW systems are of the "simple catenary" type, with 1 or 2 catenary wires supporting 1 or 2 contact wires, and with all conductors under regulated tension. Note that, where it became necessary to regulate either the catenary or the contact wires (for various site-specific reasons), the general policy was to *regulate both wires*. This made the overall design/construction/maintenance work much more straightforward, and importantly, it avoided the possible confusion if one wire only was to be regulated.

In 1993, a single page edict was issued by the (then) Electrical Standards Engineer regarding *regulated* OHW, that …

"New OHW Shall Be:

270mm² Hard-Drawn Copper Catenary, tensioned to 30kN.
Twin 137mm² Hard-Drawn Copper Contacts, tensioned at 12.5kN each.
(System T/w = 588m)"

This is ***OHW System 2***, which had been in existence since about 1985 (see *Section 4.2.4* below). But for a number of years, OHW construction projects needed to justify its use (due to the additional construction costs, mainly brought on by the higher tensions).

Because of the vast improvements that OHW System 2 offered over its single contact alternative, this important edict was essential, and it had to come from a high level in the organisation. From then on, reasons had to be given as to why it was *not* to be used on any particular future project (until more recent times).

The edict went on to say ...

This type of OHW is preferred for the following reasons:

- Better current collection at higher speeds.
- Reduced electrical losses (15% less than 270/193 system).
- Less contact wear (lower maintenance costs).
- Higher current rating (15% more than 270/193 system).
- 137mm² contacts are easier to install than 193mm².
- 137mm² contacts require less maintenance (less 'kinks').
- 137mm² contacts 'stretch' less than 193mm² over their lifetime.
- Less heating of twin contacts by stationary trains.

In addition to the above, I could add:

- Improved pantograph security (controlling the pantograph), by providing an additional 75mm (half the 150mm contact spacing) when compared to a single contact system.

This configuration made it into the first "OHW Standards for the Electrification of New Routes", EP-000801-ST in 1993, along with OHW system 12 (regulated *twin catenary* system for areas requiring even higher power), and OHW System 9 (regulated *single contact* system for situations needing less power and for low speed crossovers and siding runs).

Since then however, the more recent standard EP-08000016-SP, "Designations of OHW Conductor Systems", stipulates a few other OHW systems that could be called on readily to satisfy project requirements. These now include the following OHW systems:

No. 2: **Regulated 270mm² Catenary / 2x137mm² Contacts** (the base case)

No. 9: Regulated 270mm² Catenary / 193mm² Contact.

No. 10: Regulated 165mm² Catenary / 193mm² Contact.

No. 12: Regulated 2x270mm² Catenaries / 2x137mm² Contacts.

No. 15: Regulated 2x165mm² Catenaries / 2x137mm² Contacts (*a most efficient system*), seen in *Figure 544*.

No. 28: Fixed-anchored 270mm² Catenary / 2x127mm² Contacts (for long tunnels).

4.2.1 Liverpool to Glenlee OHW

The electrification from Liverpool to Campbelltown to Glenlee was the first major regulated OHW project for Sydney. It was completed in 1968 with the first official train and opening occurring on 4/5/1968, and the introduction of the electric suburban timetable taking place on 5/5/1968. It totalled some 60km of OHW. (Apparently it was truncated back to Macarthur in the early 2000s.)

A document written by Mr A.R. Hamilton (a Construction Engineer for the project), entitled "Liverpool – Campbelltown – Glenlee Electrification", is available that describes the OHW portion of the Electrification project, including design and construction issues, costs and some of the engineering decisions that needed to be made and why. According to this document, the project *"had a double advantage in that as well as serving the Campbelltown area by Sydney Metropolitan Suburban trains, it also enabled electric locomotives to haul the large volume of coal traffic previously handled by diesel or steam locomotives between Glenlee and Rozelle (Balmain Coal Loading Wharf)"*.

Figure 526 - Liverpool to Glenlee OHW on straight track

CONDUCTORS

The tension in the catenary wire gave a system *T/w* of 349m which resulted in a low (but constant) 17.8kN tension, yielding a relatively large catenary sag in long bays. (Contrast this with the current standard *T/w* values, which are a much tighter 588m or 550m.)

The OHW system consisted of 270mm² catenary supporting twin 137mm² contact wires. It is likely that the contact wires were made from cadmium-copper as per the fixed-anchored systems of the time. The contact wires proved to wear exceptionally well over the following decades, which is mostly a testament to regulating these wires and having 2 of them in parallel – the smaller 137mm² size in the harder cad-copper metal seemed to work well here.

The conductor details are given back in *Table 7*.

Being the first regulated OHW system, the engineers had to determine suitable feeder and potential jumpers – their length and shape – so that the 2 runs of OHW at an overlap or turnout could be connected and move longitudinally in opposite directions without causing fatigue over the ensuing decades. Refer to *Section 3.1.12.5*, *Depth of Jumper* for a further description of this issue.

SUPPORT & REGISTRATION

This was the first time the OHW support & registration arrangements not only needed to support the OHW, they also had to now allow the regulated conductors to move longitudinally

(by as much as ±500mm from their normal position) as the conductor temperature changed. So, specially designed *cantilevers* had to be developed for this project. They were mostly installed on simple masts, but occasionally they needed to be on portals with their drop verticals.

The design of the cantilevers called for the use of relatively common steelwork, including pipes, lengths of chain and various small part steelwork, all of which were hot-dip galvanised for protection to promote a long service life.

I believe that, on straight track, the catenary was staggered to zero, while the twin contact wires were given their usual zig-zag staggering pattern of ±250mm. I understand this *zero catenary stagger* approach helped simplify the calculation and construction of the cantilever frames (sadly, no computers). However, the approach could not be continued into an overlap, requiring the catenary instead to be located directly above the twin contacts. (This unusual approach was abandoned after this project.)

Having been in service now for about 50 years, only recently have there been any significant problems with the infrastructure itself, with corrosion on some equipment necessitating remedial work to be performed. An example is the cantilever pipes which tend to corrode from the inside before showing any external rust marks. This problem was recently being addressed. Refer to *Figure 558* later in this document for an example of the pipe corrosion.

There were also some fatigue problems with the early version of the stainless steel tubular pull-off arms. The original version had the arm and contact clamp directly clamped to the contact wire without any pivoting action. (It seems they must have relied on the long length of arms of about 1.5m to reduce the change in angle with longitudinal wire movement, in the hope that the limited flexing in the arms would be acceptable as the contact wires moved with temperature.) Unfortunately, eventually fatigue set in at this contact wire connection.

So to fix the problem, the current practice was adopted, of welding a short vertical tube (stainless steel in this case) to the end of the arm for accepting the standard 61/2 contact swivel clamp – see *Figure 527*. This provided the unrestricted freedom of movement needed to prevent fatigue. This solution has been retro-fitted over time, but I think there may remain some locations where this has not been carried out (e.g. it may have been deemed unnecessary in areas of shorter tension lengths). The other end has a hole for connecting to a vertical pin as part of a newer post type insulator attachment arrangement (see below). So, both ends are now set up to allow each regulated contact wire to move longitudinally with temperature changes, with provision for a small amount of pantograph uplift. This pivoting action at both ends of the arm prevents fatigue.

The arms were installed in pairs, giving a 150mm horizontal spacing between the contact pair at each support location.

Initially the pull-off arrangement on straight track (with little radial load) had the pair of pull-off arms pin jointed to the top of a *pin-type insulator*, which was installed vertically at the end of a horizontal steel channel projected out from the mast. This meant that the insulator skirts, being on the underside of the insulator, could be more effective at preventing tracking across the insulator under heavy rain conditions. See inset of *Figure 529*.

However, I think there were several problems with this pin insulator configuration:

- This insulator was mounted on a horizontal *steel* channel from the mast, and it was found that the lightning performance was poor, with flashover occurring at this vulnerable insulator. The arrangement had previously been used elsewhere with a horizontal *timber* post, and the additional insulation that the timber offered resulted in superior performance when lightning struck.
- The small diameter steel pin on the underside of the insulator had less cross-sectional metal and so corroded quicker due to leakage currents.

- The Type 2A compressive strut connection at the top of the insulator placed a huge bending moment on that insulator (*Figure 528*).
- Someone remarked that the insulators would sometimes blow apart if flashed-over by lightning. Apparently, sometimes this caused the insulator end to become detached and, by rotating at the contact clamps, the arms (and parts of the insulator) would swing into the path of the next train coming along.

The situation ultimately required a different approach, so the insulators were changed over to the now-traditional approach, which uses the large 452 post type insulator (for improved insulation), mounted with its axis horizontal, and with the twin arms (*Figure 527*) independently pinned into a twin clevis steel fitting (like fitting 364/10).

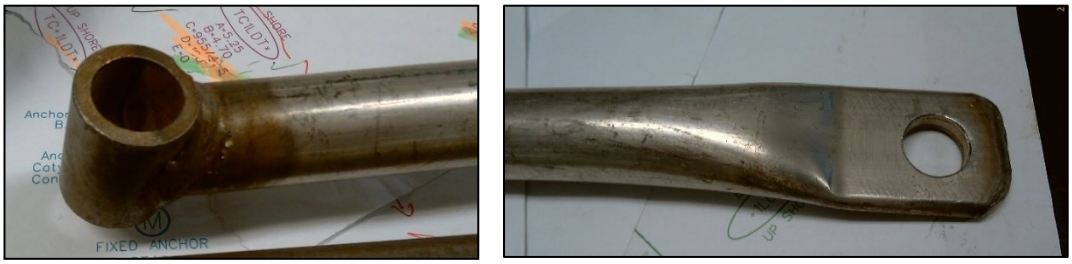


Figure 527 - Both ends of a recent stainless steel Straight Arm

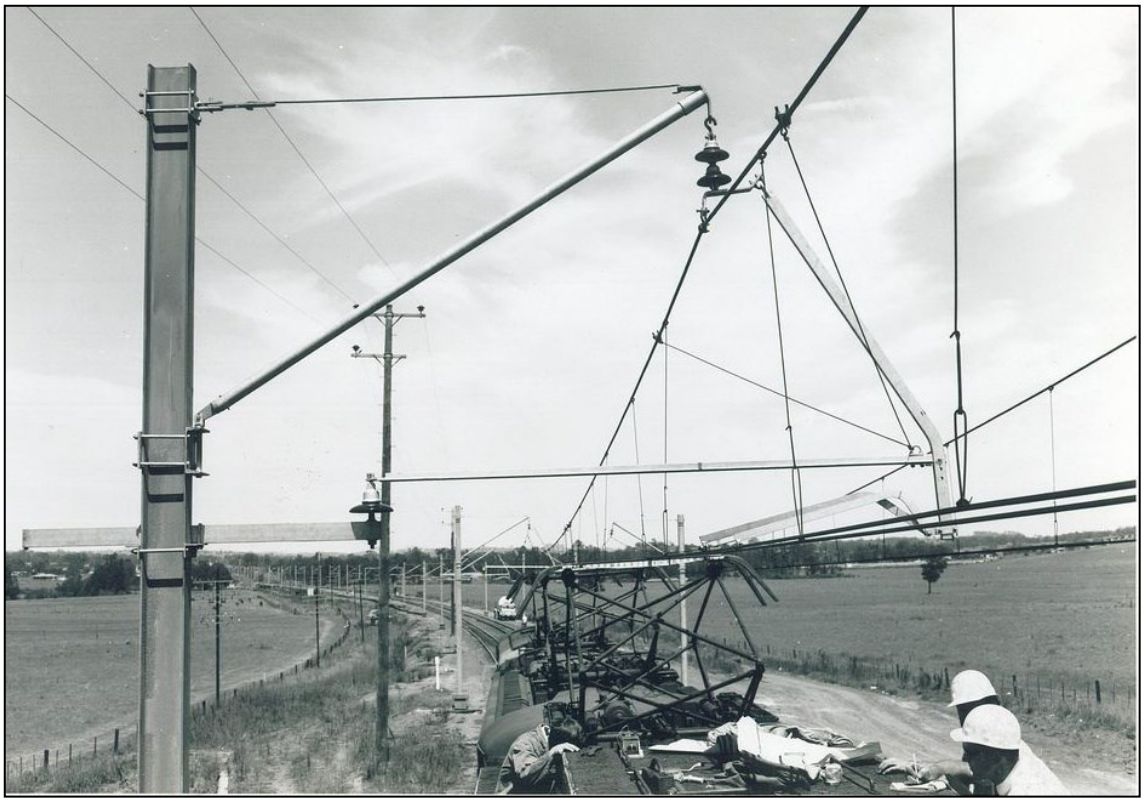


Figure 528 - Type 2A Cantilever with original Pin Insulator Registration c. 1967

SUPPORT STRUCTURES

Masts were predominantly used throughout the project where the track was straight or near-straight (resulting in small radial loads).

Tight curves required 250 RSJ type portal structures, with a braced "DR" drop vertical installed between tracks to register the contact radial load of the inner track and preserve independent registration.

ANCHORS

The *clockwork* style of tension regulator was introduced to this project, and was only for this project. See *Figure 350* much further back for what they look like.

One of the key features of this regulator was the special ratchet teeth (looking like clockwork gears), located beside the wire rope pulleys. These were intended to grab and prevent the weights plummeting to ground if the OHW conductors snapped somewhere in the wire run. They were apparently concerned about impact damage to the foundation.

However, I am told this feature didn't actually work as intended, and the weights would still fall virtually unrestrained. At least the weights were constrained, within the anchor structure cage. I haven't heard anything about impact damage to the foundation or other issues.

Note:

For additional information on this special tension regulator, refer to *Section 3.4.2.4*, *Liverpool to Glenlee Tension Regulator*.

This system also used a simple fixed anchor where a tension regulator was at the other end of the wire run.

More commonly however, were the fixed mid-point anchors located about midway between tension regulators located at both ends of the long wire run (up to 2km long). See *Figure 529*.

Here, the catenary wire was solidly anchored on each side of the portal bridge, using a snail clamp to hold the catenary tension whilst allowing the catenary wire to continue (in slack tension) under the portal to the next snail clamp. (This is much like the approach used to establish a feeder loop in the catenary wire – see *Figure 450*.)

FEEDING

If you look closely at *Figure 526* you can see aerial feeders dropping down from a cross-track aerial feeding arrangement coming from a substation or sectioning hut (on the right).

While this approach was probably a lot cheaper than installing cables out to and up the adjacent masts (as is commonly done these days), there are safety concerns using this method. For example, if the OHW for one track is isolated and rail-connected but the cross-track feeder above is still alive and servicing the adjacent track, then working on the isolated OHW may be in very close proximity with live wires above. See *Section 3.8.0.4* for more details.

GENERAL

Figure 529 shows a diesel train hauling an electric freight train for testing the mechanical path for pantographs on the Liverpool to Glenlee OHW, passing a fixed mid-point location (for both tracks).

The trackwork in this area was relatively flat, with lots of straight track and very few tight curves, which helped provide relatively good, stable dynamic OHW performance with trains at speed.

To my knowledge, and certainly from a design perspective, this OHW system has had a mostly favourable outcome over its life so far.

It provided a good introduction to the many benefits of regulating the OHW conductors, and most future open-route construction mandated that the OHW systems be regulated where this was a practical option (i.e. not through very long tunnels).

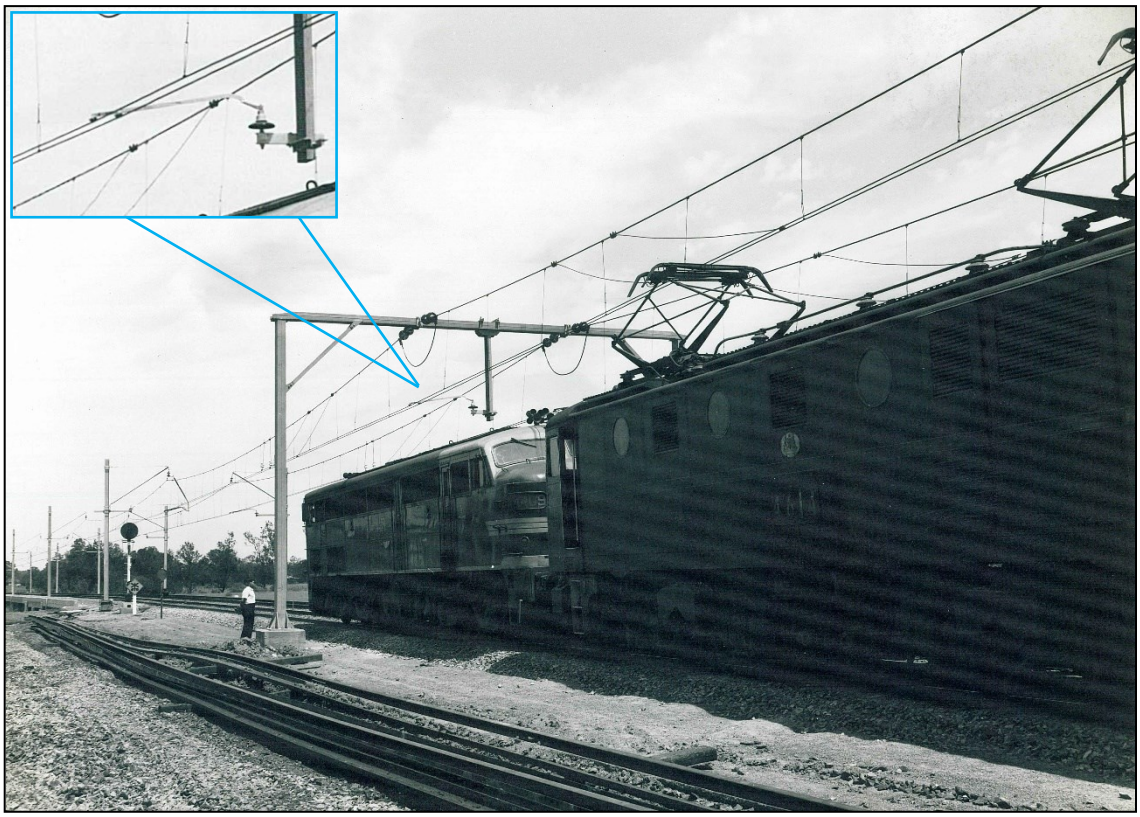


Figure 529 - Early Trials of OHW near Fixed Mid-Point Anchor c.1968 (Inset: Twin Pull-Off Arms from Pin Insulator)

However, I guess there were a number of significant improvements or simplifications that were envisaged for subsequent regulated OHW (see next section), because the system here was not replicated anywhere else in the network.

Probably the biggest lesson learnt here for future OHW systems was that the twin 137mm² contacts worked really well together (in a number of ways), and especially when they operated under regulated tension. The additional weight, under a constant high mechanical tension, seems to provide an ideal interface to the uplift force of pantographs, especially when travelling at significant speed. This basic twin contact configuration is now part of the current standard OHW system.

As far as I know, it is still performing well.

4.2.2 Loftus – Waterfall / Gosford – Newcastle OHW

The Loftus to Waterfall Electrification Project opened in 1980, and subsequently the Gosford to Newcastle Electrification Project opened to Wyong in 1982 and to Newcastle in 1984. These were the next major regulated OHW projects.

Both projects used totally different configurations to the Liverpool to Glenlee OHW. They reverted back to single contact, and the cantilevers (called Mark-1 cantilevers) and tension regulators were quite different, as well as other major equipment (discussed below). I guess that the experience gained from building the Liverpool to Glenlee Project must have shown up areas where things could be improved, simplified or made less costly.

These single contact regulated OHW system were also used at various other locations throughout the electrified network when the OHW needed upgrading, or in smaller areas requiring electrification. It became less popular beyond 1985 because of the superior support & registration arrangements offered by the Mark-2 cantilevers at this time (see *Section 4.2.4*).

Figure 530 - Completed Loftus to Waterfall OHW

CONDUCTORS

Instead of twin 137mm² contacts, these projects used the single larger 193mm² contact wire. The contact metal was hard-drawn copper which, although not as strong as cad-copper, has a reduced resistivity which helped improve the current rating and allowed higher dc circuit breaker settings.

The conductor system for *Loftus to Waterfall* was:

- 270mm² catenary wire, tensioned at 15.6kN (giving a *T/w* = 371m), and a standard height of 7.2m at the supports,
- 193mm² contact wire, tensioned at the same 15.6kN, and standard height of 5.2m.

The conductor system for *Gosford to Newcastle* was:

- 327mm² catenary wire, tensioned at 16.5kN (giving a *T/w* = 344m), and a standard height of 7.3m at the supports (the extra 100mm to help compensate for the reduced *T/w*),
- 193mm² contact wire, tensioned at 16.5kN and standard height of 5.2m.

The various system conductor details are given back in *Table 7*.

The normal standard contact height throughout the network is 5.0m (in the old days it was 5.03m or 16'6"), however these projects adopted 5.2m. I understand it was planned that the extra 200mm height was to allow for the future replacement of timber sleepers with the thicker concrete sleepers, giving an eventual contact height of about 5m.

In hindsight, the relatively low 16.5kN catenary tension used in the Gosford to Newcastle project (resulting in a small system *T/w* value of 344m), should have been much tighter.

It was shown that the relatively low catenary (and contact) tension, combined with the series of Type 2A cantilevers (handling the negative radial load) installed for the track on a constant but slight track radius (at Ourimbah), and the operation of electric freight trains with all pantographs raised, led to significant dynamic pantograph/OHW interface problems. This in turn caused the traffic speeds to be reduced in the area. (Up to 4 locos, each with 2 pans per loco = 8 pantographs in close proximity, which is a recipe for uplift problems anyway.)

After investigation and some rectification work, the problem was eventually improved, and it was virtually eliminated later when electric freight trains were removed from Sydney's network. The far greater spacing between the pantographs on the interurban trains, along with the improved dynamic and damping characteristics of these pantographs, resulted in a much more stable and forgiving outcome for these trains.

The big lesson from this – keep the conductor tensions as high as practical! (Refer to *Section 3.2.1.5, "Mark-2" Cantilevers* and *Section 4.2.4, Conductors* for more details.)

For whatever reason, the 193mm² hard-drawn contact wire used on the Gosford to Newcastle project has been stretching over the years. Most of the stretch is normally taken out after the wire is initially run – by over-tensioning this wire for a period of time – and this was done. But generally, the wire continues to stretch by small amounts each year.

This wire stretch shows up as rotation in the tension regulator *equalizer bars*, from their normal vertical orientation (the catenary wire anchors into the top hole of this bar). Indeed, they have been seen to rotate to such an extent that the bar jams, preventing any further rotation. Ideally, well before it reaches this condition, the equalizer bars are meant to be brought back to vertical (or ideally, to lean back a little in anticipation and accommodate some future stretch, before being corrected again).

For further details, refer to *Section 3.4.2.5, Equalizer Bar Prevents Further Rotation*. The diagram in *Figure 358* says it all.

SUPPORT & REGISTRATION

The various new style of cantilevers – known as "Mark-1" cantilevers – were developed to allow easy installation using readily available steel pipes, chains, etc. You can see the evolution of the cantilevers from the Liverpool to Glenlee OHW system. These cantilevers were described in detail in *Section 3.2.1.5, "Mark-1" Cantilevers.*

The cantilever "Types" were based on 3 ranges of radial loads, and whether the radial load was acting away from the support mast (+ve) or towards it (-ve, which is less inherently stable). Most cantilever Types worked reasonably well, however there were a few issues with some variants – except for one.

Unfortunately, the Type 2A arrangement (right-hand side in *Figure 530*), with its steel diagonal/vertical "crank" (which places the pull-off arm on the remote side of the track), seems to have mostly been kept from the previous design. This arrangement had a few stability problems as discussed in *Section 3.2.1.5, Type 2A Problems*. (These problems would be overcome in the later "Mark-2" cantilevers of the Waterfall to Pt Kembla Project, and they remain the current Type 2A standard arrangement.)

SUPPORT STRUCTURES

I was told that, due to the shortage of money at the time leading up to the Electrification of Gosford to Newcastle, designers had to find ways to provide an OHW system at minimal cost to make this project viable. This apparently led to the decision to adopt the Type 3 – 3A "two-third span" arrangement, which only required 2 simple masts installed, instead of a complete portal structure spanning both tracks and with a drop vertical located midway.

However, in order for the mast pair to work, the Type 3 and 3A *radial loads* around tight curves needed to be minimised, and this in turn required the catenary and contact wire tensions to be as small as practical (because radial load from a wire is directly proportional to the tension in that wire).

This may have been the reason for adopting the reasonably low 16.5kN tensions in both conductors.

Also, as mentioned in *Section 3.2.1.5*, *"Mark-2" Cantilevers*, this action would lead to the loss of "independent registration", which was to become a big operational reliability issue in the 1990s and onward. (The improvement was actually realised using the Mk-2 Cantilevers from 1985.)

OHW structures were mostly 250 UC "planted posts" (PPs) which were cheaper to install. They required a hole to be bored into the ground of suitable diameter and depth, then the placement of the mast in the ground with a large amount of concrete surrounding it, and with its pedestal formed above ground to prevent water pooling and accelerating corrosion of the mast at that level.

Any highly-loaded masts demanded 310 UC steel, including some instances of Type 3 cantilevers (which took the opposite track Type 3A radial and wind loading too). The OHW designer provided the bending moments at each location to civil design, who then determined the required mast section.

ANCHORS

Having identical tensions in catenary and contact wires was readily achieved by using a tension regulator with an equalizer bar having equal pivot spacing, with tension applied by a single tall stack of weights.

Figure 531 - Trial Tension Regulator on Wood Pole at Telopea

After the Liverpool to Glenlee Electrification, development work was carried out for a simpler and improved tension regulator. It seems that, after some trials at Telopea (see *Figure 531*), a new tension regulator arrangement was adopted for future regulated OHW systems. Note in this figure, how the 3 pulleys are independently attached, whereas the subsequent (now standard) version has 2 pulleys installed on a common set of side plates that connect to the anchor mast at one point. So, there's several advantages with the current tensioner version.

The subsequent standard tension regulators (seen in *Figure 530*) appear to also be simpler to build, with all parts readily exposed for subsequent maintenance (compared to the somewhat

awkward Liverpool to Glenlee arrangement which has the weights trapped within the anchor structure).

There were some problems that eventuated in the mid-1980s with the use of molybdenum disulphide grease packed into the tension regulator pulley taper roller bearing assembly. There were no external signs of any problem, but some of the pulleys became totally seized.

As I understand it, the unusual combination of extremely high bearing loads but with very slow speed operation of the tension regulator pulleys (of only a few rotations per day), required a special grease. Bearing experts at the time recommended that molybdenum disulphide was the best grease for this application, and it worked well, provided *moisture* did not enter into the bearing. However, the rubber seals that kept the moisture out tended to perish over time (accelerated by UV radiation exposure), and so sometimes the rubber cracked, allowing moisture in. The moisture-laden grease caused fairly rapid internal corrosion. As I recall, some samples taken down and inspected at the design office showed that the individual hardened steel rollers had corroded to virtually nothing, and most of the inside was just black powder.

In this situation of a seized bearing, it is likely that the pulley shaft itself rotated in the holes of the attached side plates when a large enough out-of-balance tension finally overcame the shaft to side plate friction. This would probably have resulted in a partly fixed-anchored / partly regulated tension behaviour in the tension length of OHW throughout the day, with potentially disastrous consequences for a system designed to be fully regulated. And it affected both the catenary and contact tensions due to the installed equalizer bar.

There were also cases of insufficient grease being applied, and the grease drying up and no longer acting as an effective lubricant.

To overcome the perishing rubber seals on existing assemblies in the field, special stainless steel UV shields were designed for retro-fitting. They are mandated for installation on all of these tension regulators – on both new and existing pulleys.

Note:

> In regard to the potential problem with grease, maybe a better outcome would be to immerse the bearings in a bath of oil (not grease). This would provide lubrication throughout the bearing as it very slowly rotates during the daily cycles. In this case, if the seals eventually perished, oil would slowly leak and provide obvious external signs of a problem, that could then be readily planned for subsequent corrective action.

It is critically important that the pulley bearing assembly be correctly put together, as it can have a big impact on the delivered tension, which in turn affects the performance of the OHW conductors and ultimately the interaction with the train's pantographs. To this end, in 2012 the old design drawing of the pulley assembly (fitting 601) was redrawn onto 2 drawings and included clear step-by-step instructions on the correct bearing assembly method, including the packing of grease and installation of seals.

One big lesson, learnt for future systems, was to galvanise the individual weights that make up the weight stack. Even though rusty cast iron weights (that were used initially) themselves pose no real long-term problem (other than aesthetics), when they're installed on a galvanised support rod, it makes it impossible to tell whether the bottom flat steel plate that's welded to this vertical rod is rusting away at the vital connection. This plate holds all the weight, but is hidden from view by the bottom weight. Failure of this plate would be dangerous. (This rod has also been improved.)

More details can be found in *Section 3.4.2, Weight Tension Regulator*.

Many of the fixed mid-point anchors relied on a cross-span linking the catenaries on opposite tracks together. This was done to help balance the radial loads of the anchor bridle wires for each track, and to remove or reduce that load off the masts. This was effective on straight or near straight track, but was less effective in situations on tight curves – adding to the already high combined radial and wind loads delivered back to the mast on the outside of the track curve.

One of the problems that was encountered at least once in the Gosford to Newcastle area, was the 165mm² anchor bridle wire that clips onto and restrains the longitudinal movement of the catenary. Not only did the large sag of this bridle wire to anchor tend to make it less effective at restraining the catenary movement, apparently it also caused havoc with a pantograph because it was so low. This is explained further in *Section 3.4.5.5, Anchor Bridle to Catenary*.

The humble fixed anchor arrangement in the regulated OHW generally did not cause grief, no doubt due to its simplicity.

4.2.3 Eastern Suburbs Railway Viaducts

The Eastern Suburbs Railway (ESR) was completed in the late 1970s. For the various tunnels along the route from Town Hall to Bondi Junction, fixed-anchored OHW was quite appropriate, considering the slightly cooler conditions inside tunnels. See *Section 4.1.4*.

However, where this wiring came outside onto the several interconnecting viaducts, it was decided that these areas of OHW should be regulated, to better cope with the hot temperatures caused by exposure to the sun, even though these exposed areas were relatively short in length (only several hundred metres or so).

This resulted in regulated System No. 5:
270mm² Catenary / 2 x 137mm Contact OHW.

To my knowledge this system, with its relatively low 19.43kN catenary tension and 9.72kN tension in each contact wire, has not been used anywhere else in Sydney.

CONDUCTORS

The conductor details for System No. 5, including tensions, are given further back in *Table 7*.

The fixed-anchored tunnel OHW was terminated at overlaps located immediately outside the tunnels, and regulated runs of OHW, of the same conductor configuration as inside, connected in between the tunnels.

SUPPORT & REGISTRATION

Figure 532 is a picture of the unique style of OHW cantilevers developed for the special portal structures installed on the viaducts.

The catenary is supported from a short solid steel frame with twin vertically aligned pivot pins at one end that then connect into a hinge fitting, then to the portal bridge. The other end has 3 holes for catenary suspension adjustment to get the correct stagger (and allow for some limited future adjustability).

Figure 532 - Special ESR Cantilevers

While the adjustability seems inadequate, the track is locked in position so that, provided the initial geometry of the OHW was correct, there should be no need for later adjustment (unless of course something else changed).

The contact registration uses a more usual solid post, however even this is of fixed length so there's no provision for adjustment except to use different length pull-off arms.

As far as I know, these cantilever arrangements are not used anywhere else in the network – a one-off solution to this unique situation, in a highly visible area near Sydney's CBD.

SUPPORT STRUCTURES

Because of the aesthetic sensitivity of the area surrounding these viaducts, special architecturally designed portal structures were developed and installed onto the viaducts.

These structures took on a curved shape, and this required the development of special cantilever arrangements to support and allow longitudinal movement of the regulated conductors (described above). Refer to *Figure 532* which shows the specially designed curved portal structures.

ANCHORS

Gas tensioners were initially used to regulate the OHW located outside the tunnels, and they worked reasonably well except for their leakage problems over time.

As I understand it, when the gas leaked out, the OHW started to behave more like a fixed-anchored OHW system (depending on the extent of leakage), and this could lead to unpredictable pantograph security issues. As a consequence, there seemed to be occasional uncertainty whether these gas tensioners were working to keep the wires properly tensioned.

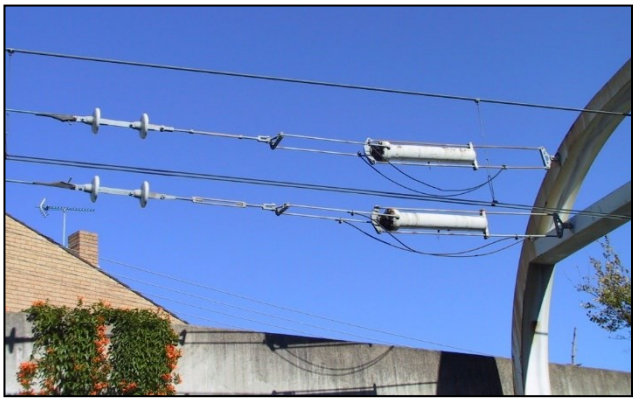


Figure 533 - Now defunct Gas Tensioners

Tell-tale signs of tensioning problems were the leakage of oil from the units, or the units being fully extended. *Figure 533* shows such a pair of fully extended, non-functioning gas tensioners.

Maintenance of these gas tensioners also required specialised training because they were deemed a *pressure vessel*.

However, eventually they became so unreliable that it was decided to replace them with standard weight tensioners, and the redesign took place around 2010. See *Figure 534* for example.

Figure 534 - Gas Tensioners replaced by Weight Tensioners (Art Gallery of NSW in distance)

The changeover to weight tensioners brought with it a high level of assurance that the OHW conductors were being properly tensioned all the time.

A simple standard fixed anchor is installed to terminate the catenary and contact wires at the remote end of each regulated wire run.

Because of the relatively short wire runs, I'm reasonably sure there are no fixed mid-point anchors in this scheme.

Refer to *Section 3.4.3* for more details on gas tensioners. There are now no gas tensioners remaining in Sydney's OHW system.

OVERLAPS

Refer to *Figure 535* for the basic make-up of an outside overlap used in this project.

Fortunately, this particular overlap was non-sectionable.

There are other overlaps that are feeding, and they require much more elaborate equipment in order to achieve the required electrical clearances etc., plus the cable feeds to and across the portal structures.

Figure 535 - Overlap on ESR Viaduct

4.2.4 Current "Standard" OHW Systems

The Waterfall to Pt Kembla Electrification Project commenced in about 1983 and opened in 1986. It saw the introduction of a number of big improvements to the previous "standard" regulated OHW system, including the significant benefits realised from using *much higher conductor tensions* (in line with "world's best practice").

The higher tensions, along with the need for other improvements, necessitated the development of totally new standard support & registration arrangements – the *Mark-2* cantilevers. These essentially remain current today for supporting any new open-route OHW.

Figure 536 is a photo taken at Beecroft on the Main North Line, after the old fixed-anchored OHW was replaced by new regulated OHW to the current standard. The steep track gradient is depicted further on in *Figure 675*. The left (Up) track has single catenary (System 2) whereas the right (Down) track (on its steep uphill grade) has twin 270mm² catenaries (System 12), of course both systems with twin contacts. Weight tension regulators at the overlaps are installed on the closest structures. (Note that the Type 2 cantilever, closest on the left, has a *mushroom head* fitting instead of the correct *guitar head* fitting that provides 3 holes for attaching the catenary insulators – a pity about the QA.)

Figure 536 - Recent OHW installed at Beecroft (c. 2010)

CONDUCTORS

Past experience had suggested that a regulated 270mm² catenary supporting 2x137mm² contacts was probably the best wire combination needed to supply the trains' high power demands, resulting from the steep track grades encountered from Waterfall to Pt Kembla. I'm sure the final decision to use this wire system was made in conjunction with some type of load flow analysis confirming its suitability.

Overseas experts had recommended that the conductor tensions be increased dramatically, to deal with the relatively poor dynamic performance experienced in some of the previous OHW systems, and bring the OHW in line with "world's best practice".

Tensions were generally increased right up to the 3:1 safety factor limit. This meant the 270mm² catenary tension almost doubled – from about 16kN up to a mammoth 30kN (about 3 tonnes). The contact tension increase was less dramatic – it went from about 11kN to 12.5kN (which is about 3.7:1 safety factor when new).

The contact wire is a wearing component, which needs to be condemned and renewed when the safety factor reaches about 2:1, so the wear from a safety factor of 3.7 down to 2 gave a reasonably practical life before needing renewal. (Experience has shown this wire to wear exceptionally well with the sliding connection of the pantograph carbon strips.)

Since the Waterfall to Pt Kembla project, there have been, and are, several available conductor configurations utilising this basic system, making it quite adaptable to the specific power needs of any particular line or area. Due to some rationalisation, not all of them are acceptable now, e.g. those with catenaries of 327mm² (System 8) and 510mm² (System 7) are no longer deemed suitable.

The current configurations include:

- ***Single catenary / twin contact*** – the fundamental standard for most open route situations.
  - 270mm² / 2x137mm² (OHW System 2).
- ***Single catenary / single contact*** – for sidings and crossovers, etc. These are:
  - 165mm² / 193mm² (System 10), and
  - 270mm² / 193mm² (System 9).

  These are generally limited to relatively slower speed operation and stabling.
- ***Twin catenary / twin contact*** – for the power-hungry areas.
  - 2x165mm² / 2x137mm² (System 15), and
  - 2x270mm² / 2x137mm² (System 12).

  Refer to *Section 4.2.5* below for more information on twin catenary systems.

The conductor details for these systems are given back in *Table 7*.

Refer to EP-08000016-SP, "Designations of Overhead Wiring Conductor Systems" (or equivalent) for more details on these systems and their application.

Contact wire *presag* was also first introduced to Sydney in about 1984, to help promote high speed pantograph current collection. For details, refer to *Section 3.1.2.5*, *Contact Wire "Hog" & "Presag"*.

SUPPORT & REGISTRATION

In the Electrical Design Office, a huge effort was given to realising a markedly different set of support & registration arrangements – the *Mark-2* cantilevers.

These cantilevers were to overcome the problems of previous types of cantilevers, and be able to cope with the higher mechanical loads imposed by the vastly tighter conductor tensions (radial loads) and weights. To a large extent, they were and remain a success.

Significantly, the arrangements would adhere to the principles of *independent registration*, which basically meant using more portal structures with drop verticals located between tracks whenever the radial load required it (e.g. Type 3 loads). It resulted in the wire runs being properly segregated as much as is practical, to ultimately improve train operations.

When developing the several standard arrangements (summarised in *Figure 224* further back), one of the key principles, as directed by the Design Manager at the time, was to incorporate

pin connections wherever this was practical. This meant providing incremental adjustability, often using telescoping steel tubes, with several holes of uniform hole spacing (initially 75mm, which later standardised to a finer 50mm), and the tubes connected together with standard 16mm diameter stainless steel pins of suitable length.

This approach also included the bolted connections in side plates having multiple holes, again at 50mm spacing.

Figure 537 - Inspection of early Mk-2 Cantilevers & Wire Runs (near Helensburgh) c. 1983

An example of this the common Type 1 Cantilever on a mast, as shown in *Figure 538*. A 16mm diameter pin is installed in the relevant hole of the telescoping internal and external pull-off tubes. Also, M16 bolts (with nuts) are installed into the relevant holes in the twin vertical side plates in the vertical strut arrangement, which sets the geometry needed for the pull-off heel height.

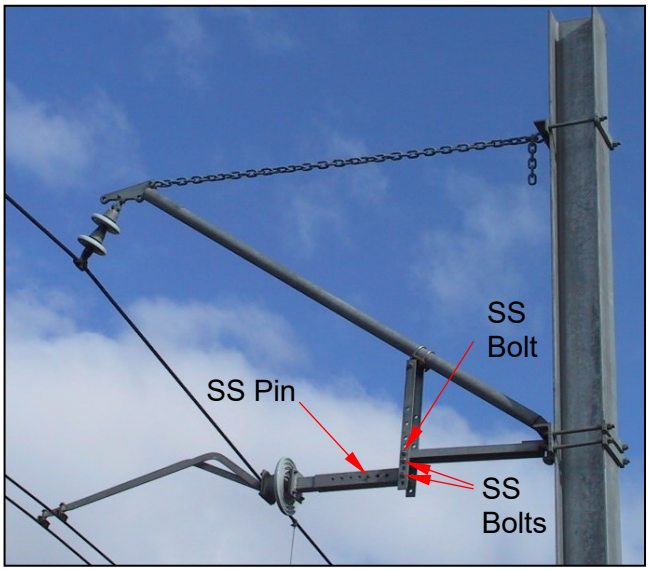


Figure 538 - Type 1 Cantilever with pinned & bolted connections

The adjustability outcome was consistent with that provided by 50mm links of chain already used at the top of the cantilevers (in use for many decades).

The resulting error in dimension using discrete hole positions is half the spacing, i.e. ±25mm. This amount of error is consistent with most important tolerances in the cantilever, including the critical stagger tolerance.

One benefit of using pins (with hump-back split pins at the ends) is that it virtually guarantees that the parts will remain connected over the life of the equipment, and not come loose and detach due to any inadequate tightening of fasteners (the alternative method of fastening).

Another benefit is that you could tell at a glance if the components had been correctly installed, because if a pin is designed for hole #2 for instance, and it's currently in hole #2, then you can be confident of that part been put together correctly. So, it generally improves quality.

Alternatively, instead of a pin, a bolt could be used to keep holes aligned in this situation, as it puts the bolt in shear (just as in the case of pin connection). And so, it doesn't depend on the correct bolt tension being applied (but the nut still needs to remain in place, e.g. using a spring washer or "nyloc" nut, etc.).

Previously, certain joined items were connected using tensioned bolts compressing one part against another, which relied on friction between the mating parts to keep them from sliding under load. (This remains the case for the several mast attachment brackets.) But unfortunately, these parts could slide if not enough bolting tension was applied during construction, and this tensioning can be quite subjective (that is, unless all linesmen used torque wrenches all the time).

Pin type connections were the way to go, to improve installation quality and overall reliability, and this approach has proven to be very effective on many types of OHW equipment over the past decades of operation now.

The *CCALC* computer program was written to generate all construction details for the installation of these cantilever. This program has proven its worth over the past almost 35 years or so. Refer to *Section 3.2.1.5*, *The "CCalc" Computer Program* for further details.

Incidentally, the policy for hole numbering the series of holes in these cantilevers, was that the numbers, starting from "1", increased from top to bottom (vertically), and from mast towards track (horizontally). This is the policy adopted in the *CCALC* computer program (and the *Mast* program before it), and in all design drawings from the Design Office over the past few decades. It's important to be consistent wherever possible.

More information is given in *Section 3.2.1.5, "Mark-2" Cantilevers*.
Also see *Section 5.1.21.1, Discrete Adjustment*.

SUPPORT STRUCTURES

Standard OHW structures were made from 250 UC beams, for masts and portal legs and their bridges. Higher loaded situations called for 310 UC structures. Multi-track situations (spanning more than 2 tracks) sometimes required double channel (DC) structures using pairs of 250x90mm, 300x90mm or even 380x100 channel sections, but this depended very much on the proposed OHW loading (communicated to Civil Design using OHW loading diagrams).

More recently, mast structures have reduced down to 200mm UC, or even 150 UC in the case of Dapto to Kiama. Unfortunately, the more slender they get, the more vulnerable they may become to *dynamic oscillations* and *resonance* generated by strong cross winds acting on the long conductor bays (and particularly if the bay lengths are mostly the same length). So, extra care needs to be taken to ensure this conductor *galloping*, exacerbated by slender support structures, doesn't have a chance to initiate. Otherwise, pantograph security may be at risk (and possibly also the structure integrity). This issue was discussed in a note earlier in *Section 3.3.0.5*.

Square hollow section (SHS) structures are also now included in the mix of steel sizes and shapes. Because of their exceptional resistance to twist, they are being used for cantilever & nose structures, portal bridges when twin drop verticals are required, etc. They have become a really useful steel section for OHW structures.

The thickness (gauge) of steel is also a variable. So, for example, the 250 UC has 3 or 4 different flange thicknesses (referenced in kg/m) and consequent strength ratings to choose from.

ANCHORS

The high mechanical tensions of the standard twin contact OHW system (System 2) required the use of 2 separate tension regulators – one for applying 30kN in the catenary and one for applying 2 lots of 12.5kN in the contact wires (through an equalizer bar).

Fortunately, the weight stacks were sufficiently compact to allow the 2 tension regulators to be installed on opposite flanges of the same anchor mast, as shown in *Figure 539*.

Figure 539 - Type 1A Cantilever on Anchor Mast (Dapto to Kiama)

When set up, the *bottom* of both sets of weights should be at the same level. This can then easily be one measure of the "health" of the tension length of the wire run. If the weights are suddenly at quite different levels to each other, then something in the wire run has moved, and this would need investigation and resolving.

Note that installing the contact anchor on the mast side that's closer to the track will result in less contact radial load on the first cantilever out in the run, and this is a good outcome.

There are several alternatives to the placement of the pair of weight stacks, including to place them on separate masts – one behind the other and linked (or not) – see *Figure 540* for instance. Here, 2 turnbuckles are used to link the 2 anchor masts together, and ensure the anchor load of the contact anchor mast is properly transferred to the guy anchor located on the catenary anchor mast.

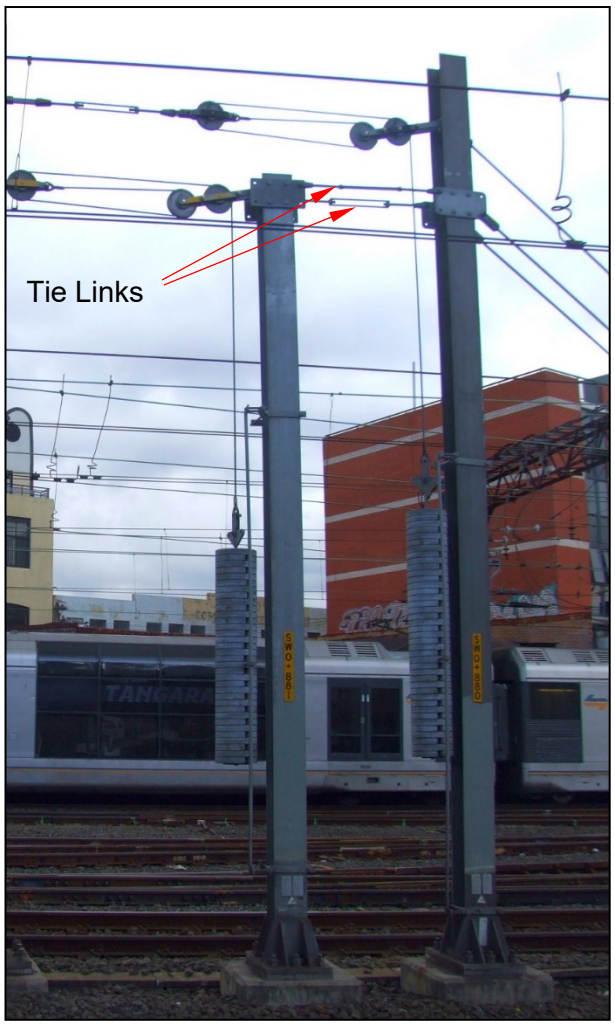


Figure 540 - Twin Tension Regulators on linked Anchor Masts (Redfern)

Note that catenary "snail clamps" caused problems *when being installed* under the extremely high mechanical tensions in the catenary wire – 30kN. (These wires were never tensioned so tightly before.) This situation is described in *Section 3.1.8.5, Catenary Snail Clamp*.

With the proper installation method used, the snail clamp should have been acceptable. But the alternative was to use helical wrap-on to clamp around the outer strands of the catenary wire, and that's what

has been subsequently installed. But now, the forked collar socket is used as the approved termination clamp.

OVERLAPS

Several standard arrangement drawings were developed for use in most overlap situations using this OHW system. They were mostly based on the in-running cantilever "Type", which was, in turn, based on the amount of contact wire radial load, namely Type 1, Type 2 and Type 3.

This assumed the overlap was to be installed on a track curve of constant radius (which was not always possible). Situations where some of the overlap arrangement was in a track transition required additional design work and documentation.

But this approach helped reduce the time it took to design the OHW for the wire runs. And it should have made constructing the overlaps more consistent (by referring to the same familiar design drawings).

However, it was eventually realised that a "shortened" overlap arrangement was needed, for situations that could not afford the length of track needed by the standard overlaps.

So, a *Short Bay Overlap* design was developed. This relied on adopting a lower out-of-running contact rise to its support location at each end of the single overlap bay.

More details can be found in *Section 3.5.0.5, Overlap Design*.

4.2.5 Twin Catenary OHW Systems

One way of boosting the current carrying capacity of an OHW system is to add an independent auxiliary feeder which runs in parallel with the main catenary wire.

Although this can be a convenient and relatively cheap solution, it can be somewhat risky, notably if the auxiliary feeder runs at a large distance from the catenary, and especially if its independent path is located away from the track being serviced, e.g. over land. For more details of the risk see *Section 3.1.1.5, Location of Auxiliary Feeders*.

The great idea of developing Sydney's first regulated *twin catenary* system came about in the early 1990s as a solution to the increased risk of installing an auxiliary feeder (which was the alternative).

The beauty of the twin catenary approach is that both catenary wires (and the contact wires below them) behave as a *unit* – they run exactly the same path, only separated by their spacing at each support (typically 150mm).

This solution came at a time when the entire electrified network was being assessed for suitable capacity for running newer trains that demanded higher energy (current) than ever before, and with an ever increasing population of trains (and passengers). Many areas of the electrified network were deemed inadequate and needed renewal and/or upgrading to a higher capacity OHW system.

The only significant issues with getting the twin catenary system adopted were:

- To come up with a means of supporting and/or registering the twin catenaries, and
- To design a suitable tension regulator configuration.

Of course, a number of standard arrangement drawings had to then be developed to show the approved configurations. This included providing a relevant *Structure Spacing Chart* for design reference. The main effort however, was in the design of 11 different support & registration drawings, moving, fixed and fixed mid-point anchor drawings, and 3 overlap arrangements.

There are now 2 standard regulated twin catenary / twin contact OHW systems:

- System 12: 2x270mm² catenaries / 2x137mm² contacts, and
- System 15: 2x165mm² catenaries / 2x137mm² contacts.

Both these system have the identical twin contact wire configurations (including tension), in common with the standard 270mm² / 2x137mm² regulated system (OHW System 2).

Examples of these systems in action are shown back in *Figure 536* and *Figure 543*.

4.2.5.1 Twin 270mm² Catenaries

OHW System 12 (with the larger 270mm² catenaries) came first, in 1993.

CONDUCTORS

Rather than using the extremely high *T/w* figure of 588m of OHW System 2, this new system adopted the slightly lower *T/w* figure of 550m (which was already a standard catenary shape for the various standard regulated single contact OHW systems – numbers 7 to 10). This led to a lower tension in each of the 2 catenaries, which subsequently reduced the mechanical stresses on the catenary anchors and the various support & registrations in the wire runs.

The conductor details are given back in *Table 7*.

SUPPORT & REGISTRATION

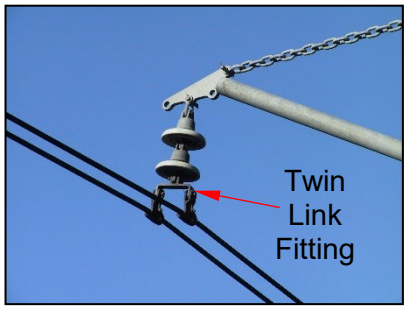


Figure 541 - Twin Catenary Suspension Arrg't

The cantilever arrangements needed to include a twin link suspension fitting, which spaced the supported catenaries 150mm apart at the bottom of the twin suspension insulators. See *Figure 541*.

One down side to this configuration is that, when the insulator swings under radial load, the individual *catenary heights change* (refer to *Section 3.2.1.5, Twin Catenary*).

The coding of the CCalc program was altered to incorporate the necessary dimensional changes resulting from this added twin link fitting.

ANCHORS

For anchoring the twin catenaries, it was decided to adopt a similar arrangement to that of the twin contact tension regulator already being used in the standard twin contact OHW System 2. But where the twin contacts needed a combined tension of 2 × 12.5kN = 25kN, the catenaries now needed 20.35kN each, totalling a massive 40.7kN (more than 4 tonnes).

Fifty-five standard weights could deliver this tension. Calculations confirmed that the required additional height of the weight stack, along with 3 times the amount of temperature-affected wire movement in 1,000m of tensioned wires (from -5°C to 60°C), plus the depth of various fittings, could all fit into the available vertical space using the standard catenary anchoring height of 7.0m.

This is probably the highest loaded anchor arrangement of all, and of course, the anchor structure needs to be suitably designed for anchoring the huge tensions and the resulting high compressive load in the leg of this structure.

4.2.5.2 Twin 165mm² Catenaries

OHW System 15 (with the smaller 165mm² catenaries) came into being in 2006.

In the late 1990s there was a considerable push to complete the many OHW upgrade project that were renewing and regulating the older fixed-anchored OHW and improving the capacity of the system, whilst also providing independent registration.

Indeed, there were many areas that had recently been upgraded to the standard System 2 (regulated 270mm² catenary / 2x137mm² contacts), with the expectation that this would be sufficient for the immediate future.

However, a while later on, people began to question whether the current rating of the now-upgraded OHW was sufficient in certain crucial areas for the proposed new "Waratah" trains that were being purchased at the time (in huge numbers). Their higher and more prolonged accelerating current from stationary, in particular, was a big concern, and modelling of the electrical system highlighted various OHW weak spots, mostly in main line corridor areas.

The highest rated OHW system at the time had twin catenaries – System 12 (described above). This system would have been ideal to use, but the relatively new OHW structures that were already installed were designed for the loadings of OHW System 2, and not for the significantly higher mechanical loadings of System 12 (i.e. greater weight, radial and wind loadings).

The ideal solution for this problem was to develop a new, lighter, twin catenary OHW system, which could provide superior current rating than System 2, but without the huge mechanical loadings of System 12. In this way, auxiliary feeders could also be avoided as a way of boosting the current rating of the existing wire (which would likely have overloaded some structures anyway).

Thus, the 2x165mm² OHW system (System 15) came into being. Importantly, it exerted about the same mechanical loadings as the already-installed System 2, but provided superior (37% greater) current rating than System 2.

Figure 542 gives an idea of how closely matched the sizes of catenary and contact wires are. This helps to force all 4 conductors to bear about the same current burden, yielding a similar temperature rise for each wire (without causing one wire size to severely limit the system current rating).

Apart from the changed fittings to take the smaller 165mm² catenaries, it is almost identical to the twin 270mm System 15, which had been developed some 13 years prior.

So, the big benefit was that conversion to this new OHW system was unlikely to overload the relatively new structures already installed, thus providing the necessarily higher current rating with few (if any) structure alterations, and ultimately saving money.

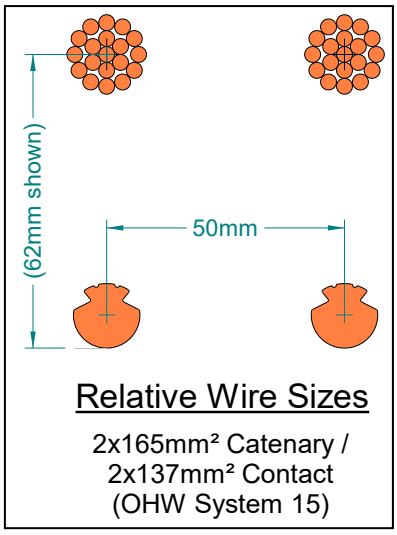


Figure 542 - System 15 Relative Wire Sizes

This twin catenary OHW system was recently installed across the Sydney Harbour Bridge for both tracks around 2012. It was seen as a way of providing the necessary "copper in the air" without putting too much stress on the various structural elements of the bridge itself, especially on the existing horizontal outrigged steel members that supported the old OHW.

Figure 543 is a photo taken after replacing the old fixed-anchored OHW with this current OHW configuration, on the approach viaduct to the Sydney Harbour Bridge. Both runs have 2x165mm² catenaries with 2x137mm² contacts (System 15). Both legs of the closest structure have a fixed anchor installed for the 2 regulated single catenary / twin contact OHW runs (System 2) heading north to Milsons Point Station and beyond.

Figure 543 - Twin Catenary OHW on Sydney Harbour Bridge Approach Viaduct c. 2012

Figure 544 is a photo taken during the construction of OHW System 15 on the southern approach to the Sydney Harbour Bridge (for both tracks). The Down Shore track (on right) has the completed new OHW whereas the Up Shore track (left) is in the process of having the twin 165mm² catenaries run from support to support.

The relatively large Argyle Substation is located on the right-hand side of tracks just before the twin tunnels in this photo. It is the OHW just outside the substation which will get the hottest, due to the *amount* and *duration* of the heavy current drawn by trains, and particularly those trains on the steep upward grade of the Down Shore track.

The 4 closely-matched conductors in OHW System 15 provide an optimum cooling solution for this situation – see *Section 4.2.5.2* for more.

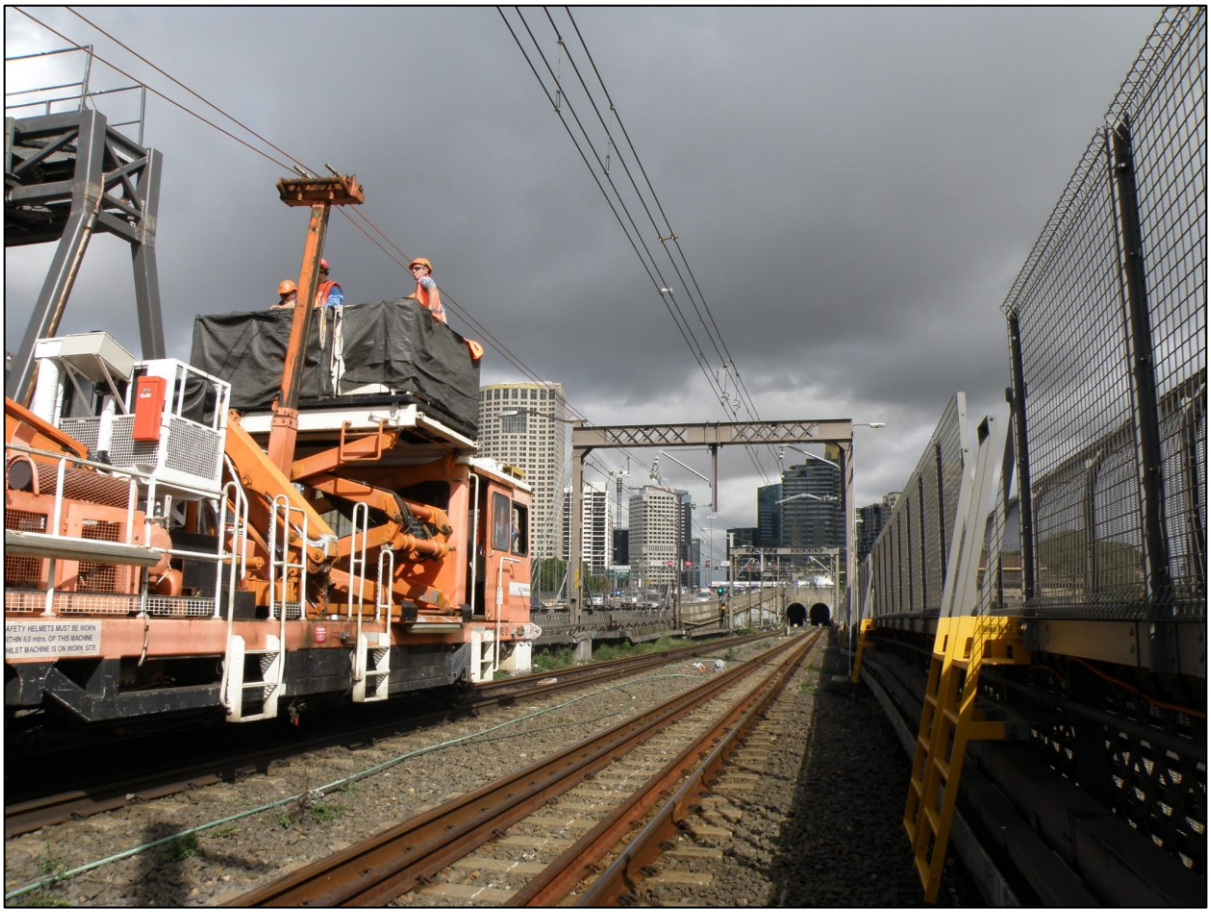


Figure 544 - Installation of OHW System 15 across Sydney Harbour Bridge
(Photo: Steve Corbin)

The superior cooling of the 4 closely-matched conductors in this system, coupled with the exposed nature of the highly elevated bridge itself (with its cooling crosswinds), should help ensure that this OHW reliably provides the necessary power for trains into the future.

4.2.6 Tunnel OHW

Regulating the OHW conductors inside long tunnels provides special challenges, which are mostly brought about by the extremely limited headroom available.

The support & registration equipment needs to be compact, and it also has to allow the catenary and contact wires to have unimpeded longitudinal movement as the conductor temperature changes, without affecting the stagger too much – a huge ask.

Then there's this issue of what type and where to install the tension regulators (bearing in mind that the conductor tensions are extremely large by world standards, driven mainly by the relatively large conductor sizes needed). If the tunnel is short enough to allow the standard weight tension regulators to be installed outside the tunnel, then this can lead to a good outcome (see *Section 4.2.8*). There are special spring tensioners commercially available that may be able to be placed on the tunnel wall (clear of passing trains and OHW), or in dedicated pockets cut out of the tunnel lining (with its risks). But they may only be capable of tensioning short runs (due to the high tensions needed).

Aside: It must be said that OHW System 28, the simple *fixed-anchored* twin contact OHW system, is quite suitable for use inside tunnels, even if one or more auxiliary feeder wires need to be run in parallel to keep conductor temperatures low. Alternatively, the solid conductor bus system also has merit (being installed in Sydney's Metro).

4.2.7 Coalcliff Tunnel

The Illawarra Electrification Project from Waterfall to Pt Kembla in 1985 called for all main line OHW to be regulated, and this included the 1km long, single track, Coalcliff Tunnel. Refer to *Figure 545*.

Apparently, this area required the OHW to have more copper, so the new OHW for the tunnel was regulated, rather uniquely, as 2x270mm² catenaries with 2x193mm² contacts.

So, special tunnel cantilevers were designed to suit this tight "oviform brick" tunnel. See *Figure 546*, which shows the 2 side-by-side sets of 270mm² catenary/ 193mm² contact OHW, supported by a single tunnel cantilever with pivots to allow these conductors to move horizontally as required in a regulated system. Unfortunately, this figure does not include the fibreglass pull-off arms registering the contact wires (they were only used at every second location I think on the straight track).

The tensioning was configured as 2 sets of regulators (weights), each tensioning a 270mm² catenary and a 193mm² contact wire via an equalizer bar.

Figure 545 - Coalcliff Tunnel

It seems, like all OHW on the Illawarra line located close to the sea, corrosion of the various steelwork is a problem for its ongoing maintenance. Salt laden water leaching into the tunnel has found its way onto various tunnel cantilevers and caused significant corrosion. No doubt the trains also draw the salty atmosphere inside the tunnels too.

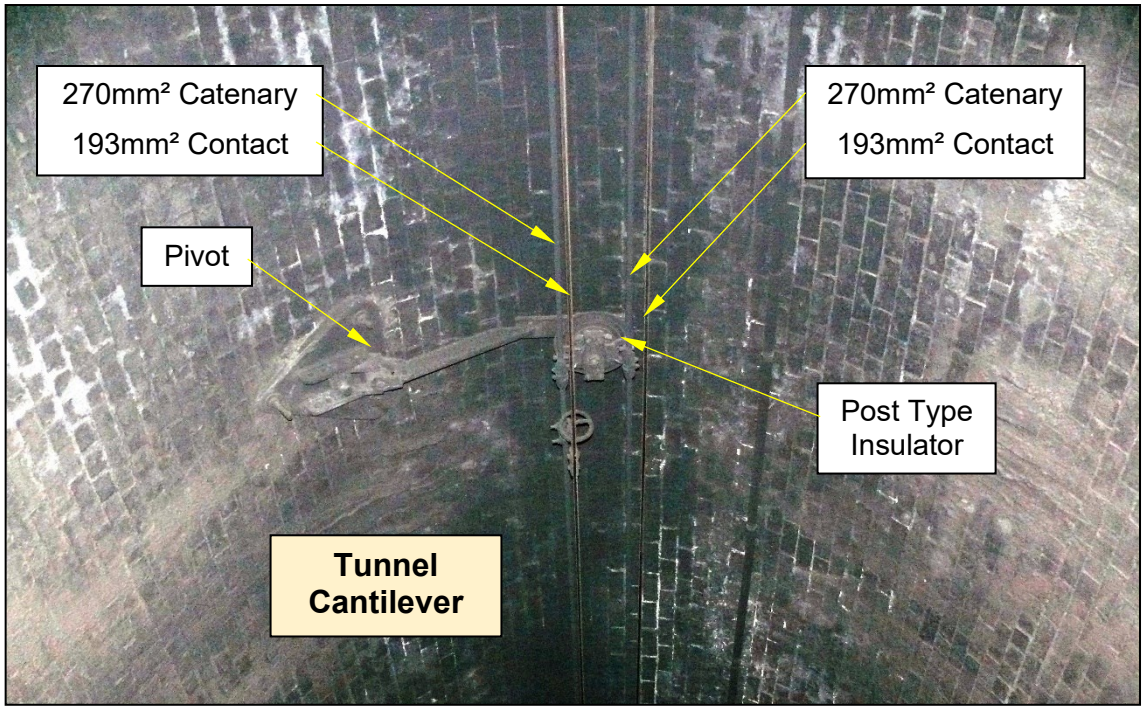


Figure 546 - Tunnel Cantilever inside Coalcliff Tunnel

CONDUCTORS

As mentioned, the conductors are essentially 2 sets of 270mm² catenary / 193mm² contact, spaced horizontally apart.

SUPPORT & REGISTRATION

Special tunnel cantilevers were developed for this project. For more details see *Section 3.2.6.4, Coalcliff Tunnel Cantilever*.

SUPPORT STRUCTURES

The tunnel is the support structure here. Special anchor bolt fittings were likely used into the tunnel lining (and beyond?), to solidly attach the S&R mounting plates.

ANCHORS

The regulated tensioning was provided by two sets of weights, with each weight stack tensioning one of the 270mm² catenary / 193mm² contact wire runs.

4.2.8 North Sydney Tunnels

The renewal of the OHW from Argyle (southern end of Sydney Harbour Bridge) north to Waverton was specified to employ regulated OHW wherever practical.

The 4 tracks through the reasonably long North Sydney Tunnels posed a problem for installing regulated OHW. This was because of the restrictive clearances, particularly in the single track tunnel areas, although only slightly less so with the twin track tunnels.

One particular area of the tunnels has had a long and sad history of "low wire" with the old fixed-anchored OHW. The Up Shore track itself, at a location just inside the single-track tunnel to the north, couldn't be lowered any further, nor could the tunnel be raised. See *Figure 71* further back, for evidence of past problems at this location – with a feeder clamp connecting the contact wire to catenary (instead of a dropper), several kinks in the contact wire and a catenary wrap-on over a repaired catenary wire – that's how low this contact wire was.

So, there was a huge push to have the entire tunnels *regulated* to prevent any future train operations problems *on hot days*.

I've included this area because of the significant challenges posed mainly by the Support & Registration needed in the tight single-track tunnels, and also because of the fixed mid-point anchors in this situation. Both these aspects required the development of new standard arrangements (which, when signed-off, could be used elsewhere in the network to solve similar problems).

CONDUCTORS

Regulated OHW System 2:
270mm² catenary / 2x137mm² contacts.

This system was selected to be the most suitable configuration for all 4 tracks in the tunnels.

The extremely tight catenary, resulting in T/w = 588m, gave only a very small amount of catenary say in the shortish bays here, which was mostly a good outcome.

SUPPORT & REGISTRATION

This project utilised the 2 types of regulated tunnel cantilevers:

- *Mark-2 TC*. This was the preferred arrangement, but could only be used in situations with a reasonable amount of head room.
- *Mark-3 TC*. This arrangement was developed for the North Sydney tunnels, in the tight confines of a single track breadloaf-type tunnel profile. See *Figure 547* for instance.

Figure 547 - Commissioning of Mk-3 Tunnel Cantilever

Note that there are strict criteria that needs to be observed when designing for the use of the Mk-3 tunnel cantilever, due mostly to its compact form. The

"Design Limitations" are listed on the design drawing EL0357173, and also described further in the document, "The New Mark-3 OHW Tunnel Cantilever", dated 23/8/2013.

For more information, diagrams and photos, refer to *Section 3.2.6.4, Mark-2 Tunnel Cantilever* and also *Mark-3 Tunnel Cantilever*.

It may be interesting to observe the relative size comparison of the above 2 tunnel cantilevers, as demonstrated back in *Figure 287*.

Figure 548 is a photo of an OHW run passing from a single-track tunnel into a twin-track tunnel (employing back-to-back Mk-2 tunnel cantilevers).

[Maybe of interest is the abandoned (fenced-off) single "stub tunnel" on the left side of this photo, which extends north for quite a distance. I understand this was meant to take one of 2 electrified tracks heading to Sydney's northern beaches (via Mosman then Manly, etc.?) as part of Dr Bradfield's vision of the future. Such a pity.]

Figure 548 - Completed OHW Run passing from single-track tunnel to twin-track tunnel

SUPPORT STRUCTURES

The tunnels provided their share of problems, partly because it was uncertain what lay behind the tunnel lining. This became a concern because the tunnel cantilevers posed a significant mechanical loading that had to be transferred onto the tunnel lining.

In the end, each location required the installation of 4 long stainless steel threaded rods that were well embedded into the lining and beyond, using epoxy chemical anchoring technology.

ANCHORS

As mentioned, the main reason why the OHW for the 4 tracks through North Sydney Tunnels could be regulated was because the standard weight tension regulators could be installed outside in the open, at both ends.

But this project required the development of an unusual fixed mid-point (FMP) anchor arrangement, so that tension regulators at both ends of each wire run could behave properly.

Each of the four FMP anchors were installed just inside the relevant single track tunnels at the north end of each of the station platforms. This was about half way along the wire runs that came close to 2km in length.

The details for these special arrangements are covered in *Section 3.4.5.5, Special FMP in Single Track Tunnels*.

4.2.9 Contact-Only OHW

One might think that regulated contact-only OHW would be useful in certain applications, instead of its fixed-anchored counterpart. But such is not necessarily so.

There's only one instance of regulated contact-only OHW that I'm aware of – at Newnes Junction for the single Coal Loader Loop track that services the Clarence Colliery Coal Loader. Sadly, with the removal of electric freight trains from Sydney's network in 2002, the OHW was no longer necessary.

Although this OHW was decommissioned quite a quite few years ago now, I include it because it shows some ingenuity in devising engineering approaches that allowed the OHW to be installed with very little monetary outlay. They even used wood pole supports instead of the more costly steel masts.

Figure 549 - Regulated Contact-Only system at Newnes

On straight track, the 193mm² copper contact wire was supported by a simple triangular frame, as shown in *Figure 549*.

However, most of the track was on tight curves (referred to as a "balloon loop"). Even though the bay lengths were short, the tight track radius resulted in significant contact radial load, which was used to advantage – the entire arrangement to support the contact wire consisted of a pull-off arm with span arrangement back to an insulator at the wood pole support. (Unfortunately I don't have a photo of the arrangement.)

In this configuration, a *large heel height*, combined with the *large and constant radial load*, was enough to support the weight of the contact wire. Very clever, but it was only suitable for the relatively slow freight train speeds encountered in the loop, and definitely not suitable for fixed-anchored OHW.

The weight tensioner arrangement is also shown in *Figure 549*.

Note that there is 1 short run of regulated contact-only OHW at Central Station, at the north end of Platform 23, but this is configured as *over-run protection* – see *Section 3.10*.

4.3 OVERHEAD CONDUCTOR RAIL SYSTEMS

I know very little of this OHW system, but for what it's worth …

Although used for decades overseas, Overhead Conductor Rail systems are a relatively new type of OHW system to Sydney. It's essentially a contact-only OHW system with no supporting catenary wire as we know it. Instead, the contact wire is supported by inserting its upper wedge shape into a continuous length of aluminium extrusion (made by bolting shorter segments of the extrusion together). The aluminium support also helps feed current to the contact wire. Its compact form means that it can be used at locations where there is very little head room, and it has other desirable characteristics.

These systems rely on an extruded aluminium section that's sized and configured to be self-supporting, only requiring supports from solid insulators about every 7 to 12m along the track route (depending on train speed, I guess).

The contact wire itself does not require any applied tension, because it is held in place by the stiffness of the deep aluminium section, which is also under no tension.

Refer to *Figure 550* for example, which shows a small sample of extruded aluminium section accepting the copper contact wire at the bottom of this section. The installation of the copper wire requires a special jig that progressively opens the gap at the bottom of the aluminium extrusion to allow the upper wedge of the contact wire to be installed, before again progressively closing and trapping this wire as the jig moves along (in a way that's similar to the action of a "zipper").

Figure 550 - Section of typical Conductor Rail

This system also lends itself to a "swing away" configuration for use at train maintenance depots. In this situation it is desirable to swing the OHW away from the centre of track over to the side of track, and thus clear the space above the train so that maintenance can be carried out on top of a train in a safer and unimpeded way.

Such a *swing away* system was implemented at Auburn Maintenance Centre in 2009, and it's installed over quite a few tracks in parallel inside the building. As I understand it, this installation is operated and maintained privately, so it may not be officially part of Sydney's OHW system(?). Refer to *Figure 551*.

This type of OHW is also quite suitable for use in long tunnels, provided the electrical resistance is low enough for the spacing of the substations and sectioning huts.

I understand that special attention is needed to prevent fatigue at the interface with this and the normal "catenary" OHW system, due to the differences in "stiffness" between the systems. (As I understand it, this is probably like the issue facing track designers, in situations where an open route track on ballast comes abruptly to a concrete bridge structure with no track ballast – there needs to be some "tapering in" of the support stiffness for the rails of a track in this area, to prevent future problems.)

A conductor rail system is now installed in the long twin tunnels of Sydney's new "Metro" North West Rail Line (in the underground section from Epping to Rouse Hill). The extent is growing further as the new driverless Metro rail system is currently being expand elsewhere in Sydney (including from Chatswood, under Sydney Harbour, towards Bankstown).

See also *Section 6.3.3.3* for more information.

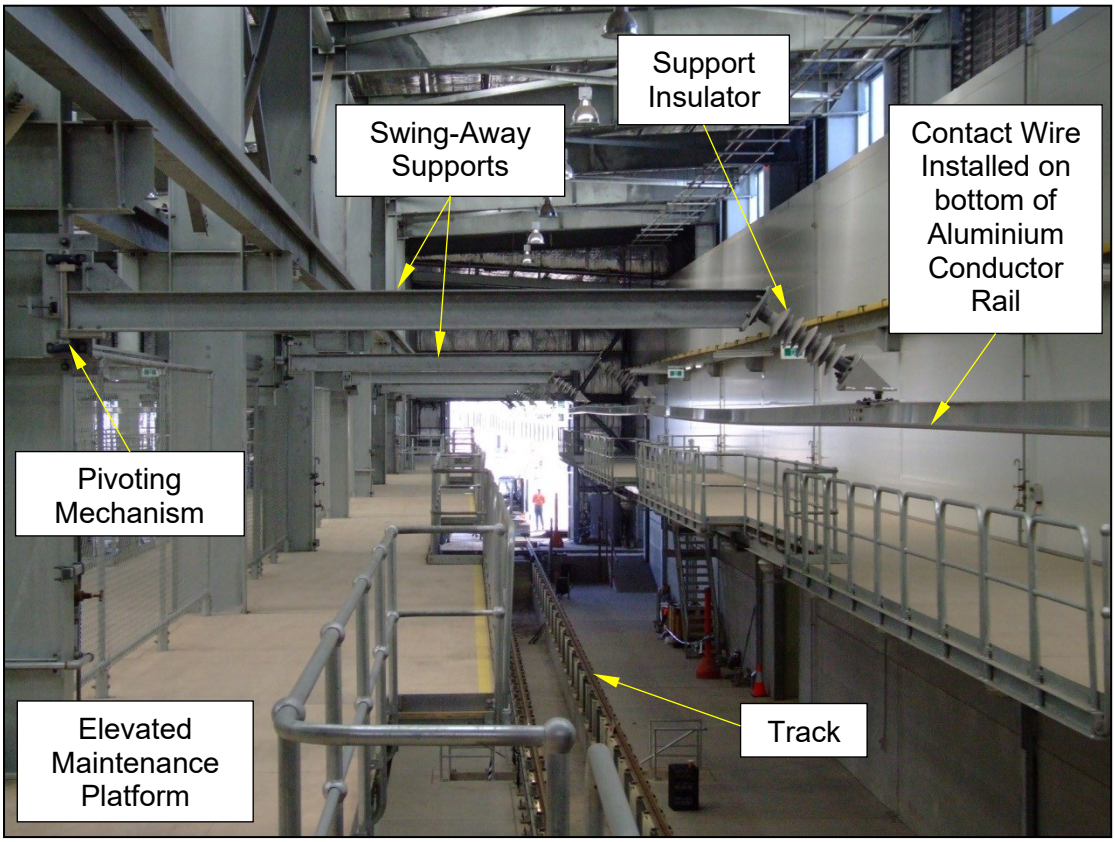


Figure 551 - Swing-Away Conductor Rail OHW system at Auburn

5 The OHW Environment

Having described the structure of the OHW Equipment and listed the main components that make up Sydney's OHW system, it's probably useful to describe a little more about the OHW environment, how the OHW operates and other factors that help contribute to its makeup and reliability.

So, the below main subsections offer some further explanations which may help in this regard.

5.1 ***Design Aspects***,

5.2 ***Construction Aspects***,

5.3 ***Operations*** ("Train Running" information),

5.4 ***Maintenance*** (aspects & environment),

5.5 ***Failure Modes***,

5.6 ***Reliability***, and

5.7 ***Some Safety Aspects***

Due to space limitations in this document, very few of these aspects go into any significant detail, but hopefully they can help develop a better understanding.

5.1 DESIGN ASPECTS

5.1.1 Preamble

OHW supply for trains is a relatively stable technology, dating back over 100 years. It's humbling to see readily identifiable OHW elements (catenary & contact wires, insulators, pull-off arms, etc.) in some of the World War 2 documentaries from England, France, Germany, Austria, Switzerland, etc. Regulating the wire tensions was obviously a big step forward at some later stage.

I guess what has changed in recent times are things like the materials used in OHW, such as fibreglass and more importantly sophisticated resins for insulators, and maybe better contact wire alloys, etc. The various OHW systems are also likely designed, built, maintained and operated in a much more reliable and safe way these days.

Another big change is the (now) extensive use of computers to help design, construct and maintain the OHW, and also aid in its daily operations. For Sydney's OHW design office, computer programs began being used way back in the 1970s for greatly helping in fundamental aspects, e.g. in temperature/tension calculations (requiring the solving of a rather complex cubic equation), virtual span determinations and the like. In the early 1980s they began being used to calculate the site-specific cantilever support shapes and other construction details ("Mast" and "CCALC" programs), providing a quantum improvement in terms of speed of calculation, accuracy, consistency and convenience (these cantilevers must number in the multiple thousands now).

More recently, computers have found an application in the use of digital image processing and measuring technologies when installed on train inspection vehicles. They help check that the OHW geometry is within the normal operating envelope, and help to identify when certain OHW components do not appear "correct" in the field. If things don't appear to be typical, then they are included on a non-conformance report etc., for subsequent close-up inspection and rectification work at the specific locations.

The Technical Maintenance Plan process in the 1990s was intended to narrow the on-track patrols, to focus mainly on those items that are more likely to fail within certain surveillance periods, and to give quality time to their proper inspection and maintenance. This approach was intended to give a much better outcome, especially in terms of reliability, whilst reducing costs. It's a system that was intended to rely heavily on computers, with hand-held units often collecting field data to identify any problems (e.g. during regular patrols), then for carrying out subsequent hands-on checks and repairs, and ultimately giving confidence (through generated reports, etc.) that the OHW system is being properly (appropriately) looked after.

The big (and maybe insidious) change for Sydney's OHW system is that it is now being called upon to operate much closer to its limits. This is due to thermal problems directly related to transmitting more power, i.e. providing more *current* to the trains (at 1500 volts), and due to regenerative braking on trains placing a further (current) burden that the OHW has to deal with and not overheat. If it does overheat, it could cause permanent damage to the OHW (and possibly other electrical infrastructure) and significantly affect train operations for extended periods.

There is also concern by some that the steel track itself may become a problem, due to its electrical resistance when passing large return currents to the substations. There may be the potential to overheat and possibly cause the rails to more readily shift around in compression, etc. (which is outside the scope of this document). But one would think that the replacement of timber sleepers with heavier concrete sleepers throughout the system over the past few decades should help to control this situation to some significant degree.

5.1.2 The Term "Overhead Wiring"

As mentioned briefly in *Section 1.6*, it is important to differentiate the system of above-track wires that supplies Sydney's trains, from the nearby high-voltage ac system that feeds power to and between traction substations (to be later reduced in voltage and rectified to dc, to feed the trains). These 2 systems are the *dc* "Overhead Wiring" and the *ac* "HV Aerial Lines" (or "transmission lines" as they used to be called), respectively.

Maybe this demarcation of terms was needed because of the following *dc* differences to *ac*:

- The absolutely huge dc supply current that's needed to power the trains at 1500V (compare 3,600 amps dc with the few hundred amps ac flowing in the HV aerial lines, albeit at much higher voltages). See *Section 5.7.2.1* for further details.
- The fact that, in most cases, the wiring above the track consists of several conductors (catenary & contact wire/s which are interconnected using droppers and in-span feeders, to give a near-flat contact wire profile for supplying the trains). Contrast this with the simpler HV aerial system which mostly uses single wires for each of the 3 phases in Sydney's traction system, to supply HV ac between substations.
- The limited forms of electrical protection on offer to protect (isolate) portions of the heavy current dc system when faults occur (and the consequent risks with this protection), compared with the more sensitive and discriminatory ac protection schemes. See *Sections 5.7.2.2* and *5.7.3* for more on this.
- The need to deliberately *not* interconnect the *dc traction return path* with the *ac earthing system*. This is due to various serious electrolysis issues when supplying dc to the trains (especially the concern over possible corrosion of nearby steel infrastructure such as underground pipelines). In the past, electricians not familiar with the dc system have made serious mistakes by connecting the traction return path to their earth wires, without understanding the dangers of doing so. See *Section 3.12.0.5, Bond Wire is NOT Earth Wire* for more details.

So, the nature of the dc system must be acknowledged as requiring its own unique treatment – when designing, installing, changing or maintaining it, and when operating the system.

In other words, in Sydney's electric traction system, the "HV ac Aerial Lines" have never been referred to as "Overhead Wiring", as this could create confusion and misunderstanding of the important issues of the dc system. (It might have been a different matter if the trains were supplied directly with ac.)

In fact, the accepted long-term designation is "Railways Overhead Wiring".

5.1.3 Extent of OHW

The following information has been obtained from Sydney's "RailCorp Electrical Annual Asset Integrity Report, 2009-10". Although it is now quite out-of-date, it does give an idea of the size of things back then.

At that time there was approximately 1,482km of *main line* OHW, and the average asset age was 26 years.

The following lists the amount of OHW in 2010, in terms of conductor run lengths.

- Regulated OHW: 1,125km
- Fixed-anchored – Compound OHW: 208km
- Fixed-anchored – Simple OHW: 144km
- Contact-Only OHW: 3km approx.

I'm reasonably sure the above figures do not include the numerous lengths of OHW that service the crossovers, etc., so the actual amount of OHW is likely much greater than that quoted above (but I could be wrong here).

There have been a number of recent projects since 2010 that have increased the above numbers substantially, but I don't have access to the updated information. Refer to *Section 1.7* for more. A map of the electrified network as it was in 2014 is given in *Figure 8*. And the extent of OHW modernisation (c. 2011) is provided in *Figure 658* (again, sadly way out of date now).

5.1.4 High Speed Operation

I understand that Sydney's "best" OHW conductor system – System No. 2 in *Table 7* – had been modelled and determined to be suitable for train speeds up to approximately 160km/h. This speed rating was mostly achieved by increasing the catenary and contact wire *tensions* as high as is practical. This helps limit the dynamic movement of the OHW in response to passing pantographs with their significant uplift force on the contact wire (4 pantographs are typical on a suburban 8-car consist, all well spaced apart). It is likely that much higher speeds could be achieved with this OHW system, but only with a single pantograph raised (which would be highly unlikely to provide the necessary power for the train – see below).

Higher speeds above 160km/h generally require significantly more electric power (to overcome the various additional frictional forces acting against the train). But this power gets increasingly harder to deliver from a 1500V system, as the necessarily huge electric ***current*** demand becomes a limiting factor. So, to get more power for the higher speeds, you ideally need more volts, the ultimate being 25kV ac. Note that even doubling the voltage to 3,000V dc would double the available power (assuming the same current limits as now).

At higher speeds towards 300km/h, only 1 raised pantograph on the train can be tolerated by the OHW system. This is because of the large dynamic disturbance at high speed that a single uplifting pantograph can create on the contact wire (especially near mid-bay), which any subsequent pantographs on that train would then have to negotiate. So, having more than 1 pantograph raised can lead to excessive arcing and supply loss to these later pantographs, and it would likely lead to failure of pantograph and/or OHW.

Having only one pantograph to supply the entire train consist would obviously alter the whole electrical supply dynamic as well as configuration of the train. This would be a big change.

5.1.5 OHW/Pantograph Compounding Problem

In the decades leading up to the 1990s there seemed to be a strange situation that appeared to be spiralling out of control, and I'm not sure how it all started. But it had to do with the heavy nature of Sydney's OHW system, stemming from the need to use large conductors (due to the need to supply increasingly more power, especially to heavy freight trains that were operating back then at reasonable speeds).

The nature of the problem here has to do with OHW being damaged by pantographs, and the converse – pantographs being damaged by the OHW.

Through the previous decades, at various stages the OHW in certain areas would require "beefing up" because the "heavy" nature of the pantographs was causing it damage. As a consequence, the pantographs would need to get further "beefed up" in order to then deal with problems they experienced with the heavier OHW. Then the OHW would need further improvement to become even more robust (heavier) as a result, and the cycle would continue, compounding the problem in the process.

The fixed-anchored nature of most of the OHW at that stage was probably the biggest contributor to this situation. And I think section insulators were at least partly involved.

A good example of this was the introduction of the Type 6 Section Insulator in the 1980s. This French SI was quite suitable for the French OHW system, but it became damaged when used in Sydney's system, causing all sorts of mayhem when the wiring ultimately became damaged. The problem happened at the leading flat diagonal portion of the 2 solid copper side runners, where they splay out to the sides (as seen at the left end in Plan View of *Figure 402*). These diagonals became deformed when heavy pantographs with worn (dish-shaped) carbon strips passed through, leading to these areas bowing progressively inwards and becoming way out of shape and a more abrupt angle. This ultimately became intolerable to pantographs, particularly when travelling at moderate speeds and above.

The adopted solution was to locally add steel angles to strengthen the copper runners (especially in the vulnerable diagonal area), and this worked well for many years. Refer to "Runner Strengthening (MS Angle)" in *Figure 402* further back. Unfortunately, this added a considerable amount of weight to the SI, which each pantograph then had to negotiate – thus this very problem! And it also cost more to fit the modifications prior to their installation.

As mentioned previously, ideally the pantograph performs best throughout its travel if it pushes upwards against a constant downward force from the contact wire. So, any hard spots can cause a great disturbance – both mechanically and electrically – to this interface at medium speeds and above. Adding weight to the SI was heading in the wrong direction, but something had to be done about the damage to the SI.

I think there were probably 3 things that ultimately began to turn this situation around for the better (around the mid to late 1980s):

- The introduction of new lighter *single-arm pantographs* on trains,
- The *expansion of regulated OHW* throughout the network, and
- The *removal of electric freight trains* (with their several ***closely-spaced*** pantographs) from the electrified network.

These are discussed below.

IMPROVED PANTOGRAPHS

Although they offered about the same upward force (~ 130N), newer single-arm pantographs seemed to be a lighter construction and were significantly better at tracking the contact wire without arcing.

The large arm mechanism could readily cope with the large contact height excursions (such as when the contact wire lowers as a train approaches a low overline bridge). Also, the light secondary suspension on the pantograph head could better trace any imperfections in the contact wire profile [such as the ripples due to sag in the wire between droppers, notably in fixed-anchored wire when hot – refer to *Figure 59 (a)*].

And when it came to heavy point loads on the contact wire (such as at section insulators), the pantograph's reduced head mass was more compliant in these areas, so it tolerated these hard spots much better, again causing less arcing. There was also less jolting of the OHW (at SIs, etc.), which is a good thing (for the following pantographs on that train).

More details are in *Section 6.3.2*.

GREATER EXTENT OF REGULATED OHW

The extensive OHW Modernisation Project initiated around the late 1980s involved renewing, regulating and installing twin contacts in as much older outside OHW, as deemed practical.

The added weight of twin 137mm² contact wires, and their constantly high tension, offered a more uniform downward pressure (better *compliance*) to counteract the upward pantograph force throughout each bay. Regulating the OHW was a good move. And even the regulated single 193mm² contact wire was a vast improvement over fixed-anchored OHW when hot.

REMOVAL OF ELECTRIC FREIGHT TRAINS

Electric freight trains, with the possibility of 2 raised pantographs per locomotive (i.e. up to 8 pantographs all in close proximity), caused significant problems, especially to the fixed-anchored OHW, and particularly under hot weather (with slack contact tension). Indeed, the official "Working of Electric Trains" instructions documented restrictions that were placed to the configuration of raised pantographs in certain (mostly fixed-anchored) areas of the network during the summer time. More is mentioned further on in *Section 6.3.1.1*.

Even though electric freight trains had a number of advantages over diesel trains, their removal from the system (albeit for other reasons), did remove this continuing problem with the OHW (sad as it was to see them disappear). It is highly likely that regulating the OHW to the latest standard may have seen a vast improvement, had these locomotives remained in service.

So, ultimately things were done to bring the "heaviness" of the OHW down, to make the interface with the new lighter single-arm pantographs even better.

And even the need for the added strengthening of the Type 6 SIs with steel runners was ultimately considered unnecessary, so it was removed in the early 2010s (reducing its weight) – another big improvement.

5.1.6 Fitting Numbers (for Identification)

A fitting number structure was developed for Sydney's OHW system, probably way back at or near the start of electrification in the 1920s. It may have even come from England during the initial electrification years (?). It was a great idea that brought many benefits over the ensuing decades. It is an essential system when dealing with OHW spare parts and stores items.

Fitting numbers provide a convenient way of uniquely identifying specific *components* or *arrangements* of components (assemblies). These identification numbers were generated by the Electrical Design Office. There is/was a set of 4 "Brown Books" that tabulated the fitting numbers in use and the corresponding drawing number for each fitting, along with a brief description of the fitting or arrangement itself. These books also showed what fitting numbers were therefore available for generating and referencing new fittings or arrangements.

This approach was mandated by the Railways back then, but unfortunately it seems to have been ignored more recently, for a number of reasons (see *Comment* further on).

For OHW work, the fitting numbers have the following prefix/suffix structure:

XXX / YY

where

XXX is a prefix number from 1 to 999 (up to 3 digits).

YY is a sub-number from 1 to 99 (up to 2 digits). Note that sometimes there is no sub-number at all, in which case the "/" symbol is omitted. Also, in one or two rare instances I believe sub-numbers went above 99, but there was no need to do this because there were plenty of other unused prefix numbers that could be used to start afresh instead (which is preferred).

Examples of *OHW fitting numbers*:

- 954/52 – a 1.2m long pull-off arm as described in its associated fitting drawing D/80580 Sheet 1 (showing fabrication details).
- 61/2 – the standard contact swivel clamp fitting.
- 452 – an old post type insulator.
- 452/10 – the replacement for the 452 insulator.

Examples of fitting numbers used for identifying *arrangements*:

- 510/8 – The Type 6 Section Insulator body from Jacques Galland, for twin 137mm² contacts,
- 510/9 – As above but for single 193mm² Contact wire.

Note that there is a different fitting number structure for HV Overhead Line (Transmission Line) fittings, and the two numbering systems should not be confused, although some of these fittings have been used in common with the OHW system (and probably vice versa).

Transmission line fittings started with "**T**" and had a different structure for subsequent numbers.

Example:

T11/7 – This is a copper thimble used to help terminate a copper span wire around a stainless steel pin of an insulator or similar hardware. (This is also referenced in OHW work.)

For OHW fitting numbers, generally the prefix number **XXX** describes the type of equipment (although unfortunately this has not always been applied consistently over the decades). For example, 954/- series fittings are certain types of pull-off arms (for single contact systems), as are the 955/- series (which are slightly lighter, meant for twin contact systems).

The 2-digit suffix generally started from "1" (never "0"), giving up to 99 possible variants. Some fittings had no suffix (and therefore omitted the "/" symbol also) – for example, the common 452 porcelain insulator.

A few fitting numbers included some intelligence built into the fitting sub-number, for example, some contact steel knuckles used the sub-number multiplied by 50 to give the contact spacing of the particular knuckle. So, fittings 47/1 to 47/7 are knuckles with spacing 50mm to 350mm, and fittings 47/8 to 47/40 was a different shape knuckle for wider contact spacing of 400mm to a whopping 2,000mm (I hope this never gets used).

Sometimes the sub-numbers were used to reference particular wire sizes. For example, the 542/- series feeder clamp copper pad (which sandwiches between 2 conductors in a U-bolt arrangement) uses the sub-number to identify the 2 wire sizes involved. So fitting 542/11 is a pad sized for connecting 165mm² to 165mm² catenary wires, 542/35 is designed for 327mm² to 510mm² catenary wires, etc. This might prove a handy reference for some, especially when ordering or installing the parts. However, this approach sometimes caused gaps in sub-numbers which were then not utilised, making the situation much less practical. And it was not universally adopted, meaning it only applied for certain fittings, so it can be somewhat confusing in the few cases where it was used.

The general principle has been that if designers eventually ran out of fitting sub-numbers to create (i.e. reached /99), they made future fitting numbers transfer to the equivalent 900/- series.

A good example is the above pull-off arms (which have quite a number of configurations dating way back, and requiring lots of sub-numbers). The early arms started as 354/- series, so when 354/99 was reached they started afresh with 954/1.

Eventually this meant that some of the 900/- series numbers began to be exhausted. Yet there are so many prefix numbers not used elsewhere, so designers were encouraged to begin with a totally new number, e.g. 964/- series, used in the recent Mk-3 Tunnel Cantilever arrangement. Another example is the 476/- series used for the newly developed droppers in 2010. The key to effectiveness of this system is to be *consistent*.

So, in summary, fitting numbers have been adopted mostly as a matter of convenience for easy reference (especially when people are familiar with the equipment, as happens over time).

Some of the fittings are actually stamped, permanently marked or somehow labelled with the fitting number. I think if there was one improvement that would make a difference to the quality of installation work and subsequent maintenance work, it would be to ensure that *all* OHW fittings are permanently labelled with their relevant fitting numbers. Going further, maybe some should also be labelled with their vital lengths, e.g. Pull-off arm labelled with *fitting number* and its *length*.

Comment:

One of the concerns I've had over the past 20 years or so, with so many external companies now designing Sydney's OHW, is that the above fitting number system may become less used and maybe it might even be rendered ineffective for the future.

In the 2000 to 2014 period, I had reviewed a number of externally designed projects where the designers had come up with their own numbering systems for that particular project, e.g. part "A" on drawing EL xxxxxxx.

While this may allow OHW to be built for that project, unfortunately it makes keeping spares a whole lot more difficult as these unique fittings can remain somewhat hidden from the main OHW stores system.

The real pity though is that, if the new fitting or arrangement turned out to be a great idea that should ideally be used elsewhere in the future, the lack of a proper global reference makes this difficult. If it's not incorporated into the OHW fitting number system, it may even lead to other designers needlessly "reinventing the wheel" (so to speak).

The fitting number system developed more than 80 years ago for Sydney's OHW still makes good sense, and there is much to be gained by keeping it current and relevant. This only requires a relatively small effort to keep it ticking over into the future, for the benefit of the many people who need to make reference to parts of Sydney's OHW system.

See also *Section 7.1*.

5.1.7 System Insulation

There are 2 main aspects to understand about the insulation of the 1500V dc OHW system – "Basic Insulation Level" (which helps ensure the conductors can operate continually at 1500V) and "Insulation Coordination" (a controlled approach aimed to help minimise OHW equipment damage if lightning flashover of the primary insulation occurs).

5.1.7.1 Basic Insulation Level (BIL)

According to standard EP-21000001-SP, "Insulation Coordination & Surge Arrester Selection",

> "*The Basic Insulation Level (BIL) of equipment such as transformers, is defined as the peak voltage of a 1.2/50 µs wave which does not cause insulation to fail; see AS 1824.1*".

With the OHW system, it is unlikely that the various insulators would fail by flashing *through* (*puncture)* the insulation, be it porcelain, fibreglass or cycloaliphatic resin (unless the insulation has cracks that go through). The normal failure mode is to flash *over* the insulation surface. Depending on the insulation material and the amount of current involved, flashover may or may not cause the equipment to immediately fail.

5.1.7.2 Insulation Coordination

Insulation Coordination is the term used to describe the deliberate design of various (graded) high levels of insulation in an electrical system. This is done to help control or manage the behaviour of any overvoltage surges on the system, in order to minimise damage to important equipment and/or any subsequent flow-on effects of said damage to nrearby train services.

For the OHW system itself, the insulation coordination approach is mostly adopted to protect crucial equipment – in particular the various conductor *anchors* that take full tension – from lightning flashover damage, which in turn is done for operational and economic reasons, etc.

Unfortunately, because of the huge exposure of the OHW conductors to the elements, this system cannot be totally protected from damage due to lightning strikes.

In terms of lightning protection of the OHW system, there are 2 aspects to consider:

a) How to minimise the chance of a direct (or indirect) lightning strike on the OHW conductors, and
b) How to best deal with the lightning strike on the conductors, in the event that the above fails.

In terms of a), shielding the wires is one method, and offering other (preferential) targets is another approach. But with lightning, very few approaches are totally foolproof.

For HV aerial lines, "overhead earth wires", located above the live conductors, can be installed as a way of shielding and diverting lightning surges away from the important 3-phase groups of conductors below (e.g. 66kV conductors, then 11kV conductors below this).

However, it's impractical to install earth wires above the OHW conductors, as there are often so many of them installed in parallel (i.e. above each track). Instead, the 1500V OHW can benefit from other aspects to minimise the chance of a direct strike to the conductors, including having objects nearby to help shield from lightning. These objects include tall buildings, being inside tunnels, under overline bridges, in cuttings (below ground level), etc. Even the regular spacing of the tall support masts and portals can help by becoming preferential targets to lightning (although this action is by no means guaranteed).

Unfortunately, lighting has a "mind" of its own (its path cannot be accurately predicted), and it can readily overcome or bypass the various planned lines of protection that may be in place. The lines of protection are there generally to *reduce* the likelihood of a direct strike to an acceptable economic level. Chance. Statistics can help determine trends though.

So, if and when lightning strikes the OHW conductors, Sydney's system relies on *insulation coordination* – the principle of "Graded Insulation" – to help minimise damage to the OHW equipment. And it employs *surge arresters* for any particularly vulnerable but crucial equipment, such as 1500V cables.

As described in *Section 3.9*, surge arresters provide 2 valuable functions when properly designed and installed:

- They limit the *voltage* stress across the piece of equipment being protected (avoiding flashover or puncture of insulation), and
- They divert the huge lightning surge *current* to ground, to prevent any immediate damage, and also to reduce the potential damage further down the line (so to speak).

The principle of "Graded Insulation" applies to the OHW system.

This means that there are 3 "levels" of insulation, as shown in *Figure 552* (pardon my feeble drawing attempt), namely:

1. ***Anchor*** termination insulation should have the *highest* insulation level, followed by
2. ***Support*** insulation, then lastly
3. ***Registration*** insulation should have the *lowest* insulation level (but still way above the minimum level needed to reliably operate at 1500V).

The purpose of this is to try to limit the *scope* of any damage to the OHW, as a consequence of surge-related insulation failure (which, for the 1500V system, basically means lightning strike flashovers). The various insulator configurations are designed so that, if a flashover should occur across the insulators, then the arc will most likely self-extinguish (if the power remains on). As mentioned elsewhere, it had been determined through testing that an air space of 150mm should cause any established arc to extinguish in almost all circumstances. (Confined spaces where ionised air can remain are more of a concern.)

So, the most important equipment to protect are the ***anchors***. This is because, if the equipment at an anchor mechanically fails due to flashover, then the *entire wire run* will likely be damaged (fall to ground), and this can affect up to 2km of equipment (and sometimes a lot more). It can also affect OHW for adjacent tracks if *independent registration* was not employed in the area, or if there is OHW for crossovers nearby. In other words, this can involve a huge amount of equipment, that all needs to be put back together before train services can resume!

The next most important equipment to protect are the various OHW ***support*** points. If the support insulation mechanically fails, then the weight of the OHW may no longer be supported at a particular location, so the adjacent 2 bays of OHW can fall to the track, affecting operations in a local area. But this damage should take less time to repair than if the anchors were affected.

The least important equipment (or better worded – the equipment to cause the least impact by insulation flashover damage) are the various ***registration*** points (which are usually located under the supports, but not always). If the pull-off equipment fails, this usually means the wires shift out of alignment. Whatever the outcome, any limited OHW damage can usually be rectified in a much shorter time frame than in the above 2 scenarios. (This assumes the train driver stops the train before reaching the affected area. However, if he passes through, then the train's pantographs may tangle the wire and bring it down. But even so, the extent of any OHW damage should hopefully be less than the first scenario.)

Saying this is all very nice, but for this approach to work, there will likely be some damage somewhere on the OHW system, so the attitude should be:

> *If lightning strikes the OHW conductors, and if something has to fail as a consequence, then it is better that the contact registration insulation fails first, and if more has to fail then the support insulation should fail next, because the worst thing to fail is the anchor insulation, which would likely affect the entire run of OHW (and maybe more).*

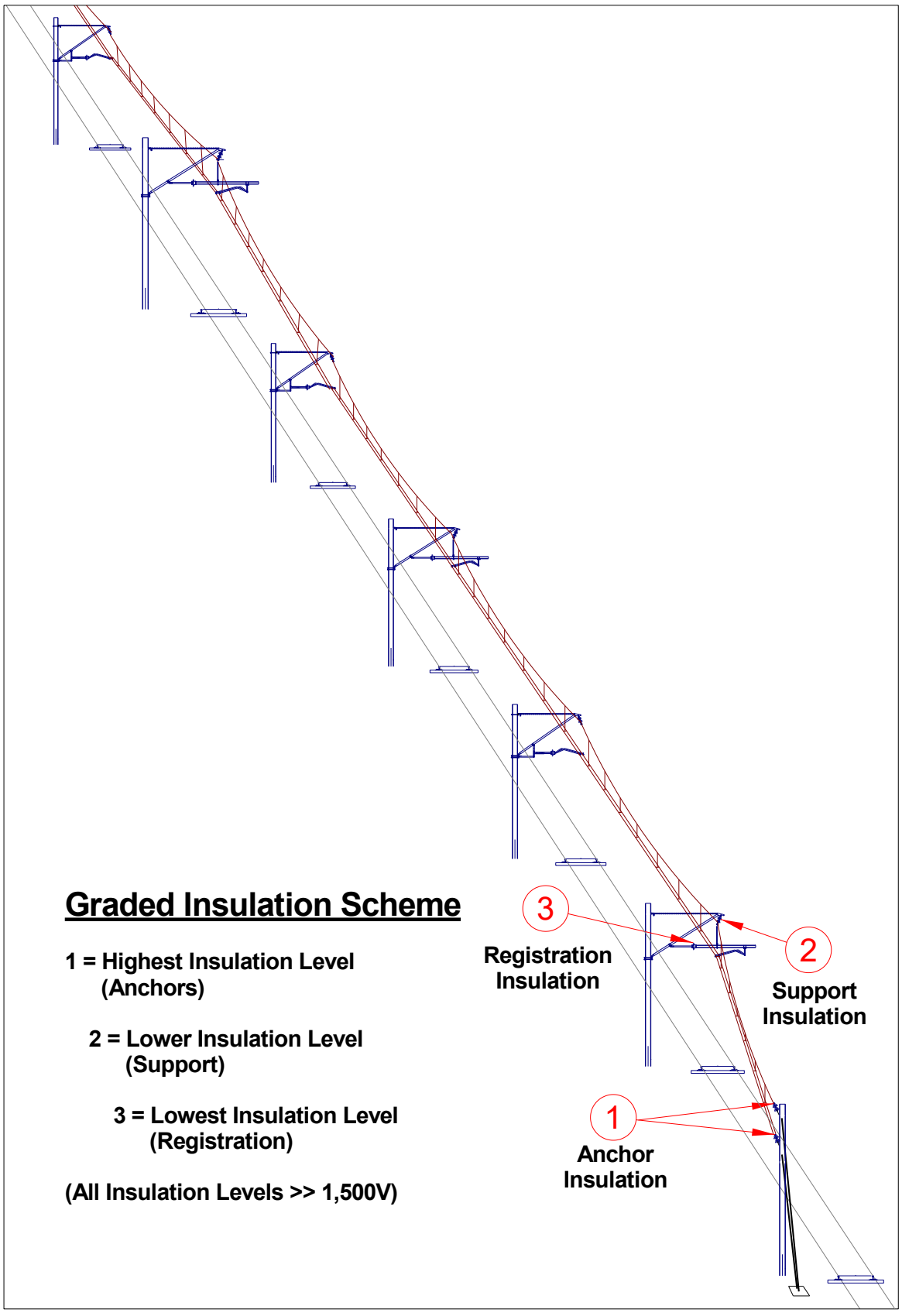


Figure 552 - System of Graded Insulation on a wire run

Once lightning has flashed over at a particular point, there should be less energy to cause further damage elsewhere down the line, since part of the energy is already lost to ground. This doesn't mean it won't flashover elsewhere, it's just that there's less energy available for it to do so. The one thing we know about lightning however is that it is unpredictable!

So, lightning damage cannot be avoided at all locations throughout the electrified network (apart from well inside long tunnels). But applying a policy of graded insulation is an

effective strategy to minimise the overall damage due to lightning, in order to get services going again as soon as possible.

The policy of Insulation Coordination has been an effective strategy for dealing with lightning surges in Sydney's OHW system for many decades now (and possibly even since day one in Sydney?).

5.1.8 Metal Fatigue

One of the culprits that can lead to unreliable OHW is *metal fatigue*. And it can be insidious.

We all know that, if you bend a piece of metal past a certain point, then bend it back to where it was, and then repeat this sequence many times, the metal can eventually break – through fatigue. Even small excursions can lead to fatigue, given enough oscillations (over time). Adding significant tension can tend to accelerate the damage (even though the metal itself might initially be strong enough for the applied loads).

Figure 553 shows an example of fatigue on an old catenary knuckle made from copper tube which is flattened at each end for drilling a connecting hole. The fatigue is shown as a hairline crack near the connecting hole. Fortunately, this damage was identified before the fitting broke. Most likely the fatigue came about because the 2 catenaries that were connected moved up and down by slightly different amounts as the temperature changed, putting a slight cyclic bending stress on this fitting. The distortion resulting from flattening the ends during manufacture, poses the weakest point in this arrangement, and that's where the fatigue finally occurred. But it took many decades for this to eventually fatigue towards failure.

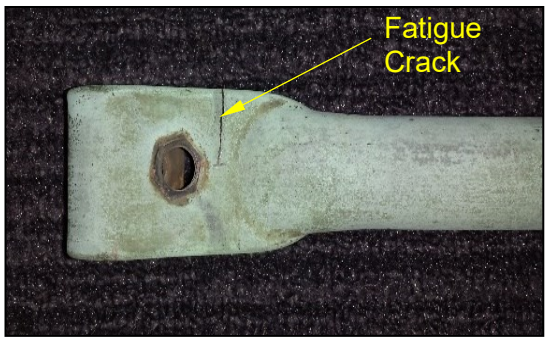


Figure 553 - Fatigue crack on a Catenary Knuckle

A properly designed and built OHW system will have taken into account the various common fatigue mechanisms. The preference of course is to avoid them altogether, but where fatigue mechanisms absolutely can't be avoided, then at least minimise their likelihood and impact during the service life (regular inspections can help here).

Cyclic movement and/or loading is the problem, and it can be due to:

- Pantograph uplift on the contact wire as the trains pass, often at high speed.
- Temperature changes, causing differential conductor tension changes and loadings, and also affecting sags and relative heights between connected conductors (as per *Figure 553*).
- Temperature changes causing the OHW conductors to move longitudinally in a regulated OHW system.
- Wind loading causing parts to flex, especially under gusty conditions.

There seem to be at least 2 approaches taken to avoiding metal fatigue in the important interface of contact wire (with its connection to the catenary) and the pantographs that uplift this wire as they pass through. In particular the droppers bear the brunt of this cyclic activity, and they need to be properly designed, made and installed. The 2 approaches are:

- To provide ***pivot connections*** through the use of pins, and allow parts to rotate under altering loads, or similarly provide ***loose connections*** that don't wear (such as the loop connections between upper and lower loops in the standard dropper).
- To ***solidly connect*** the various parts together, to ensure that they act as one unit that's strong enough (robust) to cope with any cyclic mechanical stresses.

Employing pin connections is a particularly useful method of combating metal fatigue where mating parts want to move relative to each other. In other words, if they want to move, then let them move (rather than have to deal with bending or other stresses). This approach has been used many times in the OHW system (sadly, sometimes only after the initial connection fatigued and was investigated). This is why insulator strings, connected with tongue and clevis pinned connections, have very few failures, because they can freely swing to new positions as a result of any altered forces on their end connections (e.g. catenary wire position movement due to radial load and wind load).

Example:

A good example of the use of the above 2 methods by the same fitting, is with the new contact clip, fitting 95/30 (as described in detail in *Section 3.1.3.5*, *New Contact Clamp – Fitting 95/30*. A pair of these clips connect into the upper wedge groove in the contact wire, and are tightened against the contact wire by a stainless steel cup-head bolt. But there are 2 ways of connecting this to the dropper above.

- For *single droppers*, the solid 5.38mm copper wire of the lower loop has, at both lower ends, a short right-angle bend aimed towards each other. These are inserted into holes provided in the 95/30 clip casting. When the cup-head bolt fastener is tightened against the 2-piece casting onto the contact wire, in the process it also tightens the 2 dropper wires against the underside of the cup head (on one side), and the washer (on the other side). In this way, the dropper, clip and contact wire are all tightened together and act as one solid unit – with absolutely no relative movement that might otherwise cause wear over time (with the multitude of pantograph passages). So, there should be no fatigue over time.

- For *twin dropper delrin bar* arrangement, the upper loop in each of the 95/30 castings are designed to trap a 10mm SS pin which has been inserted into the hole in the black delrin bar itself. When the contact clip is connected to the 137mm² contact wire and tightened in place using the cup-head bolt, the 2 loops rotate to the proper alignment for the 10mm pin to be accepted and trapped. This provides free sideways rotation of the contact clamp (and contact wire) in this arrangement, thus avoiding fatigue. In fact, there are 3 pivot connections with this arrangement, providing many significant benefits when using this dropper.

5.1.9 Wear on Fittings

Obviously, fittings that wear can fail if they wear out. Ideally, any situations that can lead to OHW equipment wearing over time, should be taken into account in the design of an arrangement, to limit or preferably avoid such wear. However, wear can usually be identified during the maintenance of the item, and corrective action then taken.

Sometimes it's not obvious that a situation can lead to wear (or even fatigue), especially over time (measured in years or even decades). This is primarily a design issue, but it can be affected by what's actually constructed in the field.

An example of what I'm referring to is shown in *Figure 554*, which views the end results of an incident that occurred in an overlap at Turramurra. Here, the strands of a catenary wire were worn down, apparently by abrasion over time. *Figure 555* is a picture of the Overlap Bay, and the damaged wire run. I'm not sure what the official conclusions were about this incident, but I make some observations anyway.

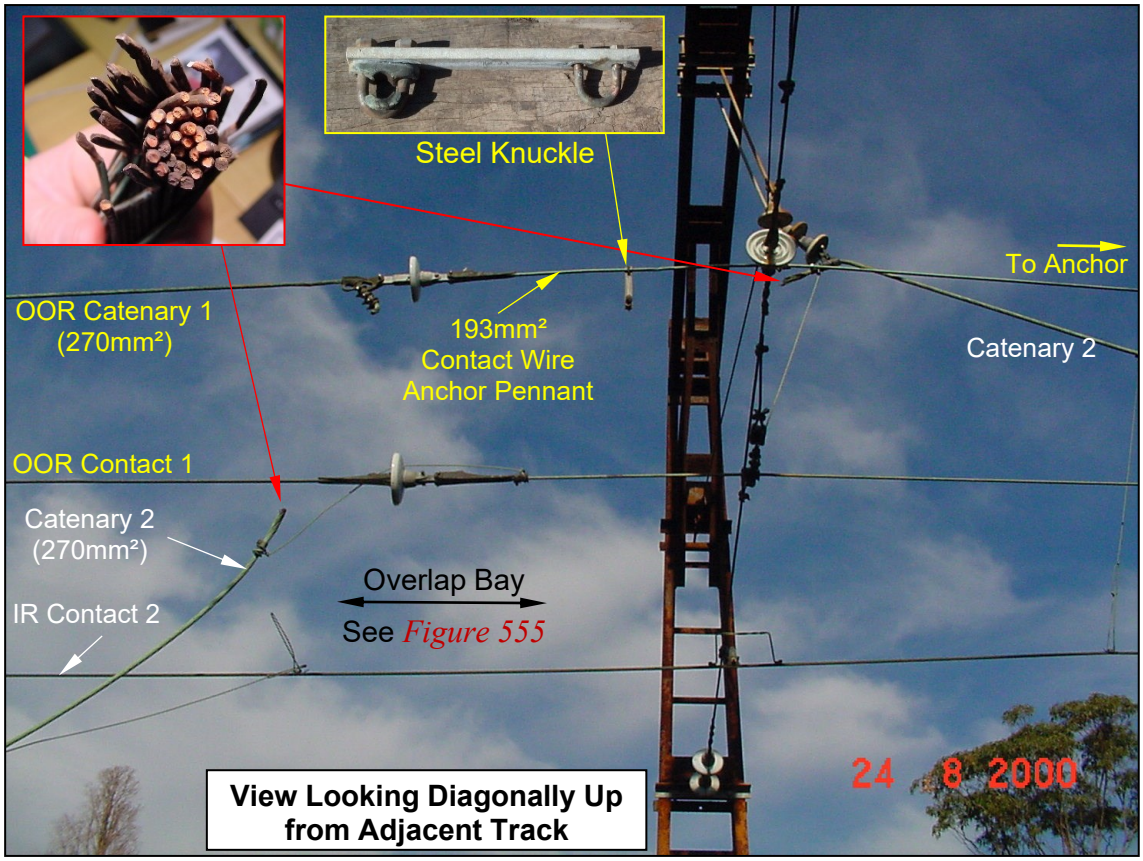


Figure 554 - Overlap In-Running Catenary worn / fatigued at Steel Knuckle

In this overlap situation, the in-running 270mm² "Catenary 2" wire snapped. Even though the 2 catenaries for the Overlap Bay are both 270mm², it was sometimes practice to terminate the OOR catenary and instead use a 193mm² cad-copper contact wire as a pennant wire to anchor, as occurs here. (It may have been easier to manipulate this smaller solid wire ?) This changeover happened at the pennant insulator. (In this Sectionable Overlap, the insulator was needed because both the in-running and out-of-running catenaries have a common span linking them at the support, so both wires needed to be of the same electrical section.)

The two catenaries are placed side-by-side, spaced about 300mm apart throughout the overlap bay. The steel knuckle is intended to help keep this separation, and is needed primarily because of the non-vertical insulator swing on the OOR catenary next to it, which can *change* its swing and thus stagger offsets with changes in temperature. This swing is a result of the radial load of this wire heading off to anchor at the next OHW structure. But even more *change* in swing results when strong winds cause the wires to blow out in either direction. Refer to analysis in *Figure 556*.

The U-bolt fasteners of the steel knuckle clamp the steel plate rigidly from in-running catenary to out-of-running catenary (actually 193mm² contact wire).

Unfortunately, there is no provision for any relative movement between these wires, so if one wire wants to move up or down relative to the other, it can cause additional stresses in one or both wires at this knuckle. The short distance from knuckle to the catenary support points (about 400mm away) also tends to stiffen this arrangement, adding to the stresses involved.

The right-hand inset in *Figure 554* of the steel knuckle, shows that the right-hand U-bolt is missing its saddle and base pads. It looks like a smaller sized U-bolt was used without these pads, but maybe instead used a copper sleeve around the solid 193mm² wire to protect it (?). The same situation on the adjacent track had the proper saddle and base pads.

Figure 555 - The affected Overlap Bay (Turramurra)

The saddle and base pads offer a soft interface between the conductors (with their somewhat vulnerable outer strands) and the steel plate of the knuckle arrangement. The pads are made from copper, brass or gunmetal, and are specially shaped (with bell-mouth curves) to prevent damage to the outer strands. They also spread the high clamping force across a far greater surface area of the conductor than can be offered by just the U-bolt itself. The greater area also helps keep the strands compact and in good order when under high mechanical loads.

My thoughts are that the U-bolt clamp around the 193mm² wire remained solidly connected, but the U-bolt clamp gripping around the 270mm² catenary wire became loose over time. This initial looseness could have resulted from the catenary's 61 strands very slowly settling in, and eventually some of the rotational movement overcame the remaining grip, and so it became loose. Once this happened, it would have been susceptible to any further periodic rotational movement, and remained loose. And wearing as well.

The tendency to rotate likely came from the change in catenary insulator swings, caused by changes in radial load (due to hot/cold daily tension changes) of this wire heading off to anchor, as well as wind loading on the 2 adjacent bays of conductors. All this is analysed in *Figure 556*, for the static case (middle diagram), and for wind blowing in either direction. The wind loading seems to cause the most rotation, totalling about 21° (= 6.8° + 14.5°).

So, the wind loading in particular, has the ability to try to twist these clamps, and the clamp that gives in first then gets looser and starts wearing its conductor over time. The nature of the rotation is shown in *Figure 557*, with the left-hand side finally giving in to twist and becomes loose (the arrows show the direction of twist), while the right-hand conductor remains tightly connected to its clamp.

This looseness, with repeated rotational movement of the clamp on the outer strands over the years, most likely caused these strands to wear and they ultimately snapped. With less strands taking their share of the tension load, the remaining strands became more highly stressed. The resulting increased looseness caused more wear on the next layer of strands, with the same result and even more stress on the even fewer remaining strands. The above incident occurred in August (winter), so the high catenary tension when cold likely exceeded the tensile strength of the remaining strands, and the catenary wire ultimately broke apart.

The close-up view on the left-hand inset in *Figure 554*, shows a number of the outer strands had flattened, probably as the strands wore against those on the next inner layer. Most of the outer strands had been worn to breakage a while ago – the damage is obviously old because the snapped area is dull and dirty. The remaining good strands holding the tension (estimated 16 strands remaining out of 61) are shown with the pink colour of copper, along with signs of the strands necking before ultimately snapping.

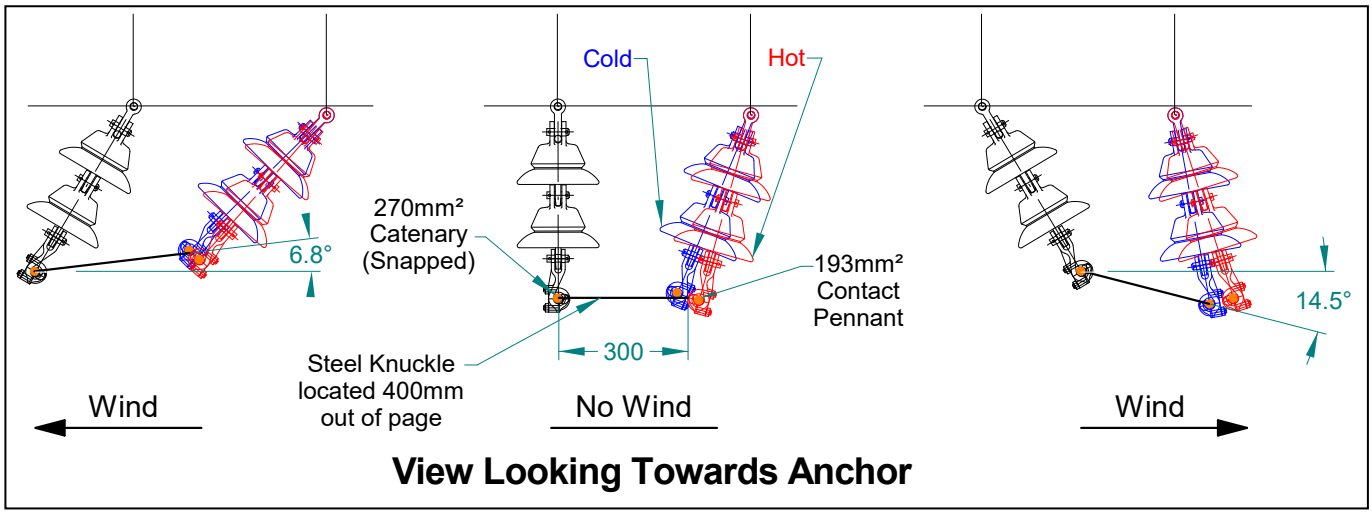


Figure 556 - Effect of change in Insulator Swing on Spreader Bar

Since the 193mm² wire is a solid conductor (one very big strand), provided the clamp was tight in the first place, this wire is less likely to distort its solid shape enough to initiate looseness with its surrounding clamp. However, the strands in a stranded wire can more readily offer such movement (due to the multitude of small pockets of space between strands).

Fatigue can also play a part in this situation (depending on the amount of relative movement).

The 270mm² catenary wire was the older 61 stranded composition, not the newer 37 stranded version currently in use. As argued in *Section 3.1.1.4*, the finer strands of the 61-stranded conductor are much more susceptible to being damaged and readily snap, which is likely the reason the 37-stranded replacement was introduced as a more robust and practical alternative.

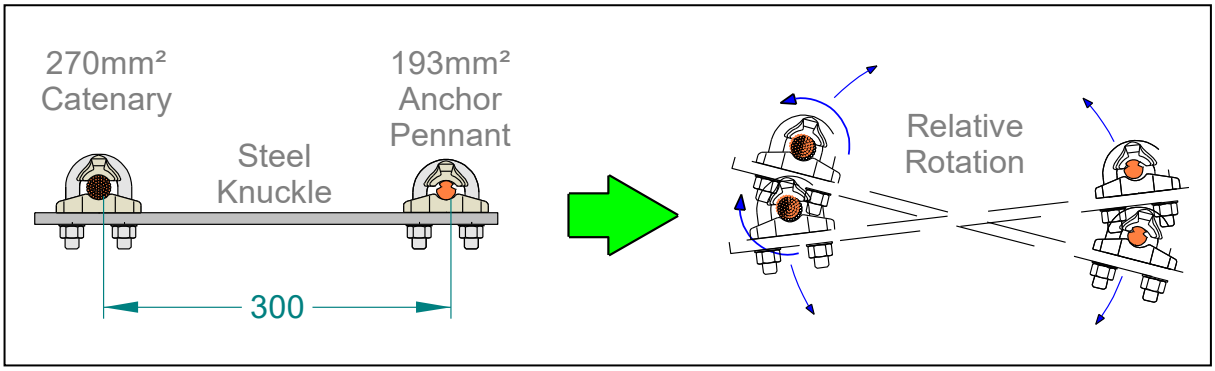


Figure 557 - Relative twist on Catenaries

Of course, the whole North Shore Line (including this example) has subsequently been renewed as regulated OHW, so this specific issue using steel knuckles will no longer occur here.

5.1.10 Corrosion

I understand that old OHW structures used to be painted with "red lead" (or similar), and there are some examples of its use remaining in the OHW system.

For many decades now, all steel components used in the OHW system have been and are *hot-dip galvanised*. This process deposits a relatively thick layer of zinc onto the steel surface to protect the steel from corrosion. This is unlike *zinc plated* steel, which only provides a very thin layer of zinc coating, and consequently lasts only a few years at best before corrosion sets in when located in the outside environment.

In the external environment the thick zinc protection typically lasts for 30 to 50 years or even more, depending on the amount of moisture, pollution and other atmospheric conditions. Refer to *Figure 558* which shows rust emanating from the inside of a cantilever pipe, making its way to the outside surface. This equipment was installed in the 1960s so it lasted 60 years. It's interesting to note here that the excessive rusting occurred at the lower end of the pipe, at a location between the pipe and its bottom-end fitting, where water can collect internally and rust.

Figure 558 - Internal rust on a Cantilever Pipe finally exposed (Liverpool to Glenlee)

If the equipment is located close to the coast, where salt in the atmosphere can be deposited onto the zinc surface, the zinc coating can deteriorate much more rapidly. With a bit of forethought, in these areas the zinc coating during manufacture can be made thicker to allow the fitting to last longer before needing renewal. This approach has been implemented in various coastal areas.

Additionally, or alternatively, the surface can be painted on top of the galvanising for superior protection. Refer to *Figure 559* which shows a portal structure located close to the salt water (Pacific Ocean) at Bombo, near Kiama. It was a contract requirement in this electrification project to epoxy coat all galvanised structures located within 1km of water, and with good reason here. Unfortunately, the various galvanised OHW parts (cantilever pipes, chain links, pull-off arms, etc.) did not get such special treatment, and these parts begin to show signs of corrosion quite quickly as a result of the salt spray. I suspect these parts in the photo had been renewed recently as they look to be in good condition.

Figure 559 - Galvanised & painted Structure adjacent to ocean (Bombo)

Another example of significant corrosion is shown in *Figure 560*.

The upper photo shows some relatively rapid and severe corrosion of turnbuckles and other parts, used for terminating the catenary & contact anchor loads. This anchor location was located within about 200m of salt water (at Circular Quay), and with wind blowing the salty water in the atmosphere, corrosion can quickly take hold.

The lower photo shows the renewed arrangement, which included new link plates, pins, insulators and turnbuckles.

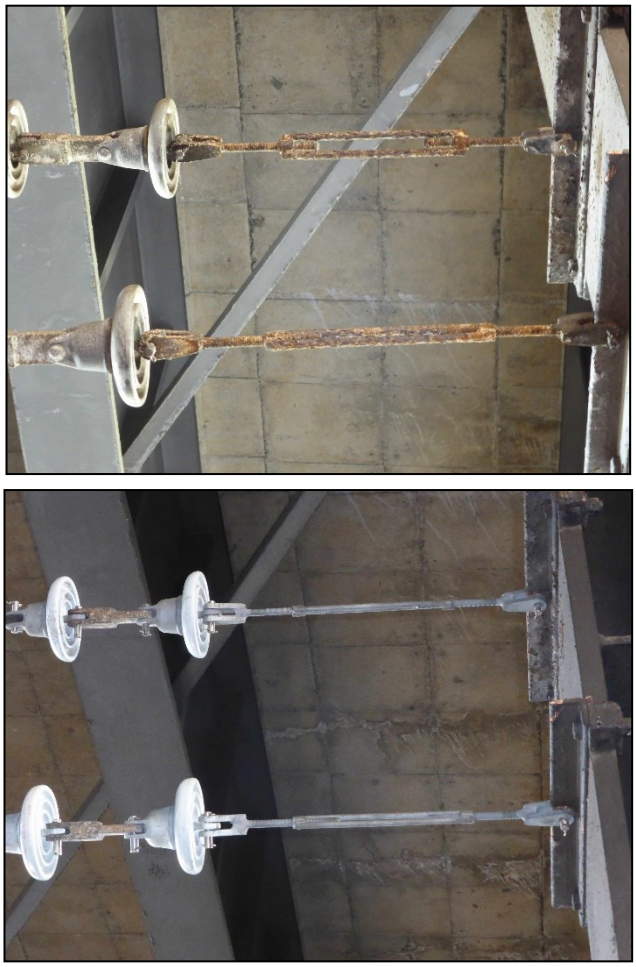


Figure 560 - Corrosion of OHW Anchor hardware near salt water

Figure 561 highlights the sort of significant corrosion damage to fittings when subjected to constant moisture, such as water leaking through the ground and into a tunnel (in this case, the Eastern Suburbs Railway tunnels).

Water passing down through the ground can leach chemicals which can rapidly accelerate the corrosion process.

See also the *example* case further below in *Figure 564* (at Epping).

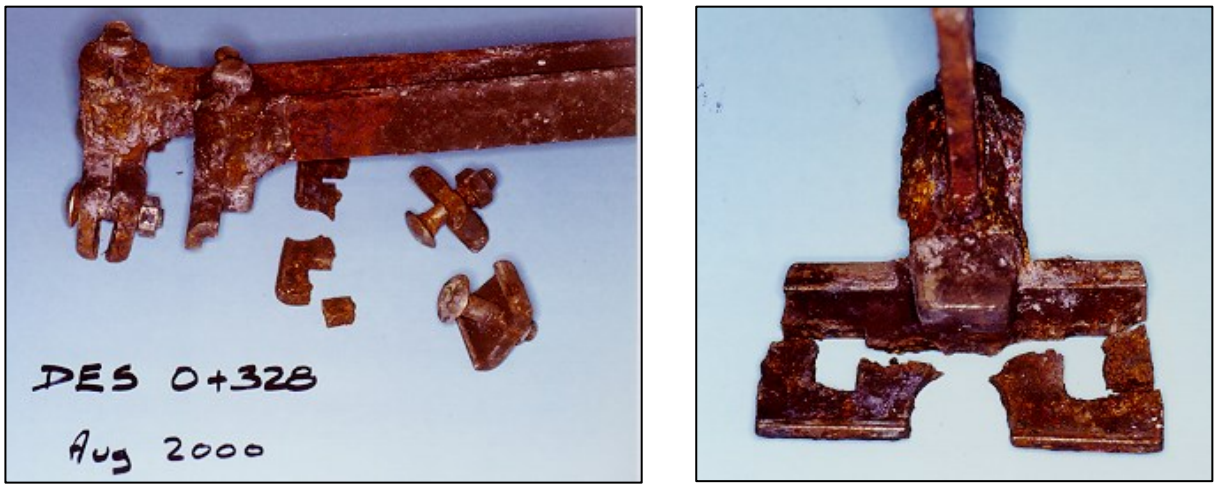


Figure 561 - Significant corrosion of Pull-Off Arm and Contact Attachment Fittings

Another type of corrosion can happen when small leakage currents pass across insulators over a long period of time (this is somewhat dependent on their cap & tongue orientation, due to the dc current flow direction). See *Figure 562*.

This type of failure is often difficult to see, especially from the ground. And even with close-up "hands-on" inspections, it's sometimes not obvious if corrosion is taking place on the small diameter tongue, and if so, how much of the metal has been affected.

One tell-tale sign is the brown rust marks leaching onto any hardware below.

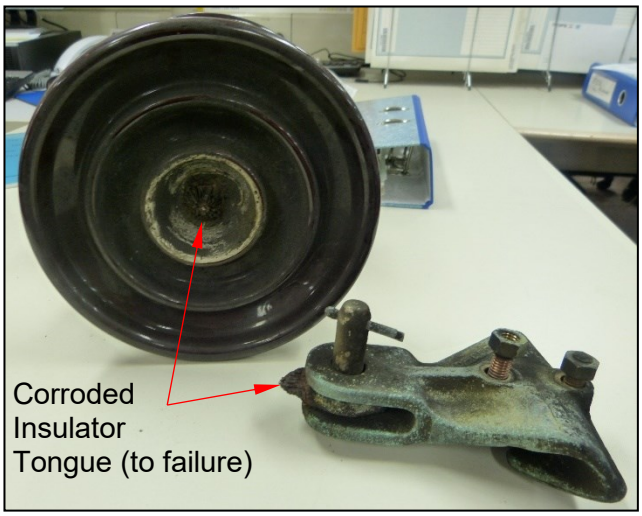


Figure 562 - Corrosion of Insulator Tongue

This type of corrosion was discussed previously in *Section 3.2.0.3* and shown in *Figure 172*.

DECEPTION

Seeing red-brown rust on a surface is a sign of significant corrosion taking place.

Sometimes new OHW cantilevers have been installed on older rusty portal structures (this was usually associated with converting the OHW from fixed-anchored to regulated at minimal cost). Because the cantilever is installed below the portal bridge, the rust colour from bridge can drop onto the galvanised chain and pipe etc. of the new cantilever, and this can cause uncertainty as to whether the cantilever itself is corroding. See *Figure 563* for instance.

Figure 563 - Rust leached onto Cantilever below

The problem with this scenario is that you initially think the cantilever is rusting and, after some effort, soon discover that's not the case. A potential waste of time.

You can then lower your guard, thinking that the cantilever is not rusting and that it's only discolouration coming from the rusty portal, and mostly this might be the case.

Unfortunately, it can disguise any serious corrosion that may actually be taking place, but regular close-up inspections may not be considered important and no corrective work carried out until a failure (due to corrosion) takes place.

This outcome is much like the "cry wolf" fable.

Another good example of this problem was discussed further back in *Section 3.4.2.5*, *Galvanised Weights*.

I see this type of scenario as a significant risk to any equipment that has a mix of old (rusting) parts and new parts.

In other words, there is much to be gained by removing any signs of corrosion that could

otherwise lead to a misconception of real corrosion taking place. The rust colour is nature's way of telling us that some steel is beginning to deteriorate and it therefore needs to be monitored more closely. Or better still, it should be repaired so there's no more corrosion, making it easier to periodically check it's still in good condition.

Example:

At the relatively new Epping underground station, one catenary suspension location continually exhibited a corrosive blue colour on the gunmetal catenary suspension clamp – the blue colour is likely copper sulphate. See *Figure 564*.

It seems that a corrosive water solution is seeping in the ground and finding its way to the chain connection at the ceiling, then flowing down the long vertical chain to the suspension clamp. I seem to remember that a motor mechanic's workshop used to be located above this area many decades ago, and it's quite possible that many years of spilt battery acid may have leeched into the ground (?). Or the corrosion may be due to other natural salts in the ground leaching through.

Figure 564 - Corrosion (in blue) of various copper-based OHW Fittings

It's likely that there will also be significant corrosion on the vertical galvanised steel chain, which can deteriorate without anyone knowing (the chain is mostly housed in a black plastic tube, probably to prevent transfer electrolysis problems to the ceiling steelwork). So, this becomes a potential hidden failure mode.

WELDING STEEL PLATES

A policy has existed for many decades now in OHW design, to have parts welded in such a way as to prevent internal spaces which could otherwise collect water and rust prematurely.

So, when 2 steel plates are welded together, the weld seam needs to encompass the entire joining area and provide a reasonable degree of penetration, to seal from moisture ingress.

In this way, moisture cannot wick into the space between the plates. (With 2 plates simply butted together, there's always a minute space.)

Note that if a hole is drilled into these 2 plates, then this hole can provide a join line between the plates where moisture can wick into the gap and lead to corrosion. Subsequent galvanising of the component cannot guarantee the join line will be sealed, and sometime the heat caused during this galvanising can distort the metal and further open the join line.

Thus, steps need to be taken during the design of the part to ensure that even the holes are effectively sealed off from moisture, by means of welding.

A good example of this approach is shown on the mast attachment bracket, fitting 361/37 series on drawing EL0033665 – see *Figure 565*. Here, 2 steel spacer pieces are welded to a main plate with continuous 4mm seal weld, and larger 32mm holes are predrilled in the spacers to give room for 4mm seal welds to be made near the smaller 22mm holes, to seal out moisture as required.

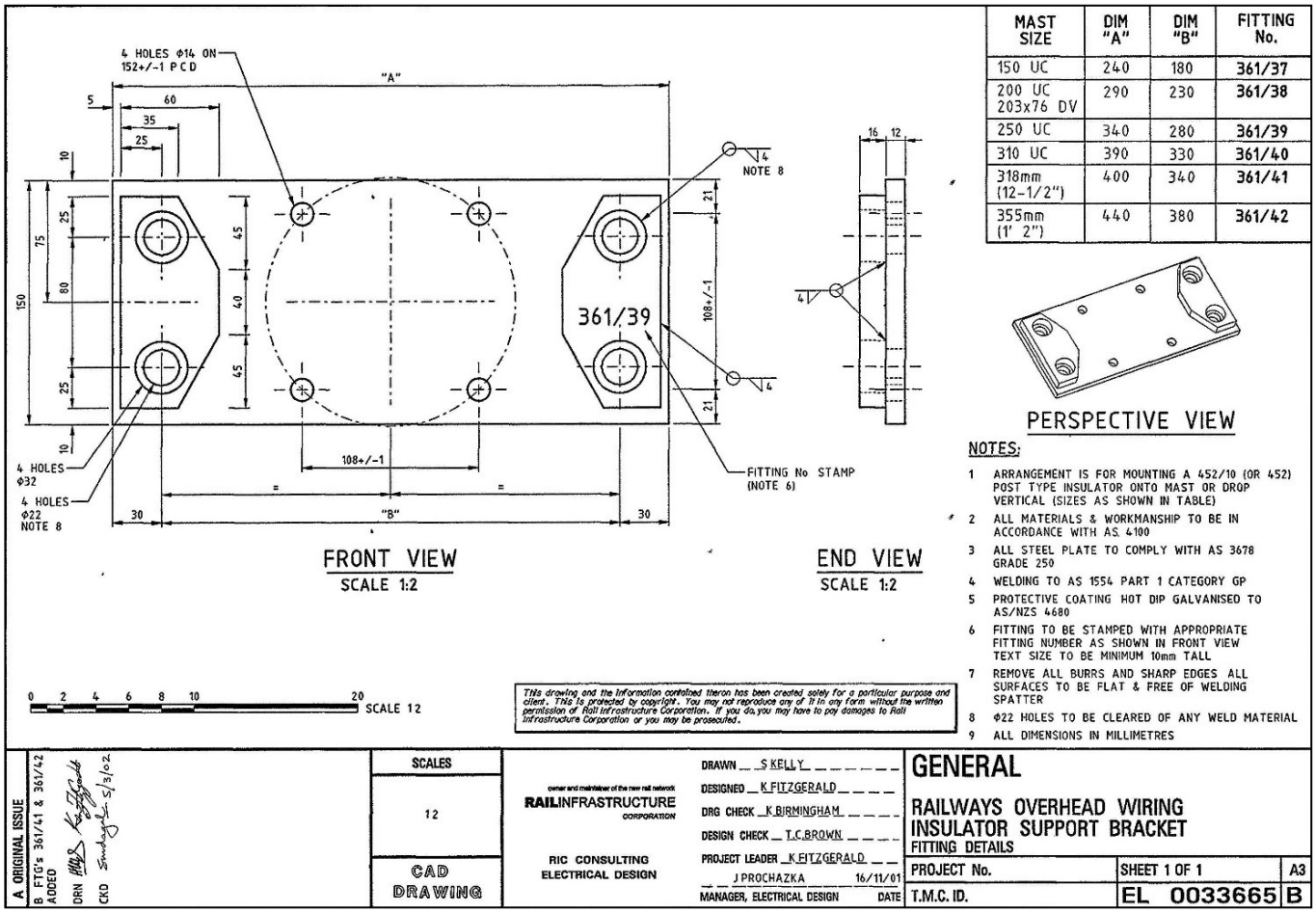

MAST SIZE | DIM "A" | DIM "B" | FITTING No.
150 UC | 240 | 180 | 361/37
200 UC 203x76 DV | 290 | 230 | 361/38
250 UC | 340 | 280 | 361/39
310 UC | 390 | 330 | 361/40
318mm (12-1/2") | 400 | 340 | 361/41
355mm (1' 2") | 440 | 380 | 361/42
4 HOLES Φ14 ON 152+/-1 PCD
4 HOLES Φ32
4 HOLES Φ22 NOTE 8
NOTE 8
FITTING No STAMP (NOTE 6)
361/39
FRONT VIEW
SCALE 1:2
END VIEW
SCALE 1:2
PERSPECTIVE VIEW
NOTES:
1 ARRANGEMENT IS FOR MOUNTING A 452/10 (OR 452) POST TYPE INSULATOR ONTO MAST OR DROP VERTICAL (SIZES AS SHOWN IN TABLE)
2 ALL MATERIALS & WORKMANSHIP TO BE IN ACCORDANCE WITH AS 4100
3 ALL STEEL PLATE TO COMPLY WITH AS 3678 GRADE 250
4 WELDING TO AS 1554 PART 1 CATEGORY GP
5 PROTECTIVE COATING HOT DIP GALVANISED TO AS/NZS 4680
6 FITTING TO BE STAMPED WITH APPROPRIATE FITTING NUMBER AS SHOWN IN FRONT VIEW TEXT SIZE TO BE MINIMUM 10mm TALL
7 REMOVE ALL BURRS AND SHARP EDGES ALL SURFACES TO BE FLAT & FREE OF WELDING SPATTER
8 Φ22 HOLES TO BE CLEARED OF ANY WELD MATERIAL
9 ALL DIMENSIONS IN MILLIMETRES
SCALE 12
This drawing and the information contained therein has been created solely for a particular purpose and client. This is protected by copyright. You may not reproduce any of it in any form without the written permission of Rail Infrastructure Corporation. If you do, you may have to pay damages to Rail Infrastructure Corporation or you may be prosecuted.
A ORIGINAL ISSUE
B FTG's 361/41 & 361/42 ADDED
DRN
CKD
SCALES
12
CAD DRAWING
RAILINFRASTRUCTURE CORPORATION
RIC CONSULTING ELECTRICAL DESIGN
DRAWN S KELLY
DESIGNED K FITZGERALD
DRG CHECK K BIRMINGHAM
DESIGN CHECK T.C.BROWN
PROJECT LEADER K FITZGERALD
J PROCHAZKA 16/11/01
MANAGER, ELECTRICAL DESIGN DATE
GENERAL
RAILWAYS OVERHEAD WIRING INSULATOR SUPPORT BRACKET FITTING DETAILS
PROJECT No.
SHEET 1 OF 1
A3
T.M.C. ID.
EL 0033665
B

Figure 565 - Fitting drawing calling for continuous seal welds

ORIENTATION OF FITTINGS

Sometimes the simple orientation of fittings can help to prevent or slow down any tendency for corrosion, by avoiding or minimising any places where moisture may be trapped. Prolonged moisture exposure can cause detrimental effects on things such as galvanised bolts (rusting), or permali beam (timber rot), etc.

This is one reason why the galvanised hold-down anchor fasteners for masts or portal legs are installed on a concrete pedestal that's raised *well above ground level* to avoid water *pooling*.

This was noted with the orientation of U-bolts in *Section 3.1.5.4*, *Insulated Knuckle*.

5.1.11 Dissimilar Metals

The connection together of parts that are made of different metals should be done with an awareness of the ability of dissimilar metals to cause corrosion or other long term problems.

The typical *galvanic series* of some metals in salty water is shown below in *Table 46*. This simple table was sourced from *Galvanizers Association of Australia*, and their website appears to be a good reference for ways to protect steel from corrosion (which is a significant issue with the OHW infrastructure, being located mostly out in the open). Refer to https://gga.com.au/.

This table helps to show how 2 dissimilar metals will behave when they come together and are surrounded by water (the electrolyte). If one metal is more *Anodic* (towards the top of the table), it will tend to corrode in preference to the more *Cathodic* metal (lower in the table) which will tend to be preserved.

The sequence of the metals is dictated by the metal's potential (voltage) value relative to some reference electrode (this is not shown in the table). The greater the potential difference between the metals (roughly the further they are away from each other in the table), the greater the dc "voltage" in this electrolytic cell (battery if you like). This potential difference drives the rate of deterioration of the anodic metal.

Metal
Magnesium
Zinc
Aluminium alloys
Mild steel, cast iron
Tin
Chromium
Lead
Brass
Ferritic stainless steel
Copper
Nickel
Austenitic stainless steel

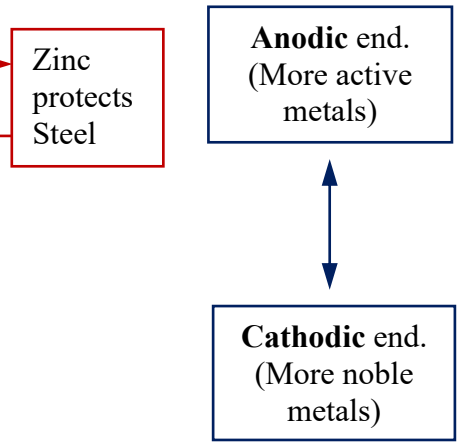


Table 46 - Galvanic Series of some metals

Put another way, those metals with higher potentials (towards the bottom of the table) are less active and less prone to corrosion – they are "cathodic".

The aim of all *cathodic protection systems* is to prevent corrosion or reduce the rate of corrosion of the cathode, by promoting the flow of electrons from the active anode to the more passive cathode. The anode supplies the current, which in the case of a sacrificial anode, causes it to gradually corrode as the +ve ions dissolve into the electrolyte.

In the case of active impressed current systems, the potential difference is created via a separate low voltage dc current, and provides a more significant protective system.

CATHODIC PROTECTION EXAMPLES

Zinc is coated onto steel to become galvanised steel. This offers "cathodic protection" of the steel, because the zinc is more anodic and it will corrode instead of the steel. So, if a deep scratch is made through the zinc into the steel, the surrounding zinc will act as the "sacrificial anode" to protect the steel (until the surrounding zinc metal dissolves away, and then the steel begins to corrode).

A zinc sleeve is fitted to the tongue of various porcelain insulators. Examples are fittings 453/13 & 453/14 – the drawings for both these fittings include the need for a thick zinc sleeve partly embedded inside the insulator and leading out along the tongue (see *Figure 34* further back and *Figure 571* further on).

If this insulator is used for catenary support (in pairs), then its tongue is connected to the catenary at +1500V. So, any dc leakage current passing across the moist, polluted surface of the porcelain insulation, comes ***from*** the steel tongue, and the zinc sleeve surrounding it is there to offer immediate cathodic protection to this tongue. This is particularly important because the steel tongue's small cross-sectional area, compared to the steel cap at the other end, makes it more vulnerable to mechanical failure.

Note that, if the cap was instead on the +1500V side (which is the preferred orientation, as is the case for most pull-off situations using these insulators), then the larger cap surface area in contact with the porcelain means any corrosion from the cap will take much longer to occur

before the insulator is deemed unsuitable and should be replaced. Also, any brown rust colour is much more obvious on the cap than on the smaller and more hidden tongue.

This is one of the reasons why L-Irons on an overline bridge are supported at both ends by a post type insulator with its cap facing upwards – this makes the cap at +1500V, allowing it to corrode in preference to the more vulnerable (and hidden) tongue. (And of course, this way the insulator sheds are located underneath and are thus more likely to remain dry.)

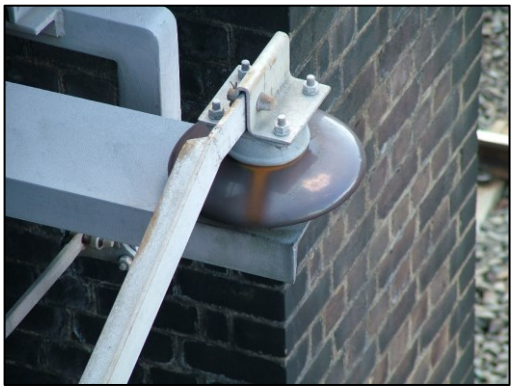


Figure 566 - Insulator Cap with brown rust stains

Corrosion of the cap at an overline bridge can be seen in *Figure 566*.

Copper cable lugs connect the copper bonding wire to a galvanised steel OHW structure. The copper cable lug should be tin-plated so as to slow any tendency for corrosion at the interface of the connecting metals. There are actually 3 lots of dissimilar metals here:

- Copper to tin (the tin plated copper lug),
- Tin to zinc (the bolted connection),
- Zinc to steel (the galvanised steel),

And it's all connected together by a stainless steel bolt.

5.1.12 Metal Erosion Due to Current

Within the "conductor" and "support & registration" equipment systems, it's important that the equipment be designed and installed to prevent dc current taking alternative paths that pass through stainless steel items, such as pins, etc. Apparently the crystalline structure of some forms of stainless steel are susceptible to damage from even small levels of dc current, and over time the metal can become brittle and even fracture under normal mechanical loads.

Sometimes you can tell that current has been passing through stainless steel pins, because it can lead to obvious metal erosion from micro-arcing as some of the load current follows this alternate path.

See *Figure 567* which shows a fairly common erosion consequence of dc current passing from the contact wire through a connected pull-off arm and its 511/32 attachment SS pin (pictured), then by other paths to the catenary. Eventually the metal will erode so much that it fails.

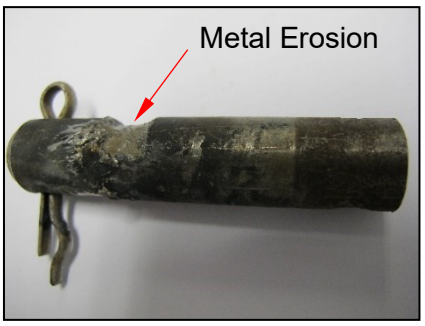


Figure 567 - DC current erosion on SS Pin at Arm

The solution is to install some form of low voltage insulation, e.g. a porcelain "loop strain" insulator (in span arrangements), or nylon insulation (as in the case of the protective sleeve between the upper and lower loops of a typical dropper arrangement). *Figure 568* shows an instance where a porcelain loop strain insulator prevents current flowing from catenary to contact wires via cross spans and the pull-off arm in this rather old arrangement.

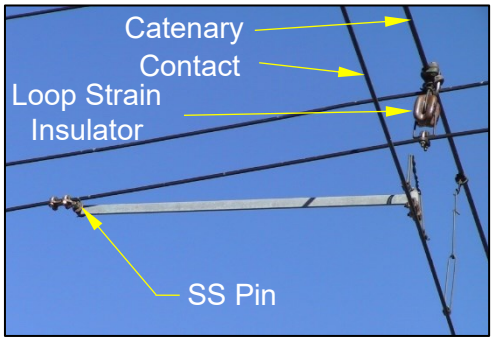


Figure 568 - Buller Insulator prevents current flow

Although this is mainly a design issue, it can become a maintenance issue later on if the intended insulation

is omitted or somehow "shorted out" during construction or later maintenance. Indeed, testing the insulation or using other methods to confirm its insulation integrity, may be necessary in each case.

5.1.13 Wire Temperature Extremes

Much has already been said earlier in this document about wire temperature and how extreme temperatures can impact on the reliable operation of the overhead wiring.

Cold *temperature extremes* used in design work can be 0°C near the coast, -5°C in the west, or -7°C (20°F) in the Blue Mountains. Cold temperatures can lead to:

- Overstressing components under the higher tensions in a fixed-anchored system, or
- Limiting how far the regulated wire can run from a fixed anchor or fixed mid-point anchor when contracted (affecting staggers and pantograph security).

Hot *temperature extremes* are generally caused by hot ambient conditions plus load current. The temperature extremes are those that either:

- Come close to causing the copper to begin to anneal (starting at about 80°C), or
- Cause unacceptable behaviour to the OHW (such as in fixed-anchored OHW, causing a large amount of additional mid-bay sag and poor pantograph performance), or
- Limiting the expanded length of regulated copper wire in a long wire run (again, affecting staggers and pantograph security, but also the tension regulator setup).

In *Table 47* below, I have summarised most of the possible adverse consequences of OHW conductors when operating at or close to their hot or cold limits.

So, the OHW needs to be designed, installed, maintained and operated within these bounds.

OHW Classification	Aspect	Extreme Cold Wire Temperature		Extreme Hot Wire Temperature	
		Fixed-Anchored	**Regulated**	**Fixed-Anchored**	**Regulated**
1. Conductors	Blowout	-	-	Too much mid-bay contact blowout – jeopardises Pantograph Security.	-
	Annealing	-	-	Catenary &/or contact wires may anneal & permanently stretch – affecting clearances & train running. Permanently reduced tensions.	Catenary &/or contact wires may anneal & stretch to failure (snap) & stop train services.
	Contact wire integrity	Badly worn contact wire – can snap under high tensions.	-	Contact wire low tension interface with pantograph at speed – can be poor, with arcing & intermittent loss of supply.	-
	Clearances	Reduced catenary clearance to overline bridge – may touch bridge.	-	Catenary sags – causes contact wire to touch top of train & stops train/s.	-
2. Support & Registration	Contact stagger		Excessive stagger change with cantilever swing – may jeopardise Pantograph Security.	-	Excessive stagger change with cantilever swing – may jeopardise Pantograph Security.
3. Support Structures	Mechanical loading	Structure must handle increased mechanical loads, due to higher conductor tensions.	-	-	-
4. Anchors	Clearances	Anchor guy, etc. must handle increased mechanical loads, due to higher conductor tensions (especially in the contact wire).	Weights may rise too far & jam on pulley – increasing conductor tensions through tension length.	-	Weights may bottom-out on ground or other impediment – reducing conductor tensions through tension length.

5. Overlaps	Contact wire geometry	Tight wire tensions may jeopardise overlap geometry – causing much arcing with passing pantographs, etc.	-	Slack wire tensions may jeopardise overlap geometry (in terms of both sag and blowout) – leading to poor pantograph performance, etc.	-
6. Section Insulators	Contact wire alignment for pantographs	Tight wire tensions may cause SI runners to go out-of-alignment – affecting pantograph performance (with possible long term damage to SI).	-	Slack wire tensions may cause SI runners to go out-of-alignment – affecting pantograph performance (with possible long term damage to SI).	-
7. Switching	Electrical clearances	-	Too much longitudinal wire movement may cause electrical clearance problems between aerial feeders (to OHW) and surrounding steelwork.	-	Too much longitudinal wire movement may cause electrical clearance problems between aerial feeders (to OHW) and surrounding steelwork.
8. Feeding	Electrical clearances	-	Too much longitudinal wire movement may cause electrical clearance problems between aerial feeders (to OHW) and surrounding steelwork.	-	Too much longitudinal wire movement may cause electrical clearance problems between aerial feeders (to OHW) and surrounding steelwork.
9. Surge Protection	-	-	-	-	-
10. Over-Run Protection	Contact wire alignment for pantographs	Tight conductor tensions – may cause runner misalignment problems, affecting pantograph interface.	-	Tight conductor tensions – may cause runner misalignment problems, affecting pantograph interface.	-
11. Signs	N/A	-	-	-	-

Table 47 - Possible adverse consequences of extremely cold or hot OHW temperatures

5.1.14 Annealing & Discoloured Copper

Copper is annealed by heating it up to high temperatures. This annealing initiates at something like 80°C while full annealing occurs beyond 300°C.

In the process of heating to annealing, the copper can take on a distinct *pink colour*. Indeed, seeing this colour on copper is usually the tell-tale sign of the copper having been annealed at some stage.

Observing this pink colour on any copper that's under high mechanical loads can bring on a panic attack to engineers who understand the significance of this situation. There can be thoughts of a highly tensioned copper wire beginning to stretch and ultimately snapping, bringing down vast lengths of OHW (this is particularly relevant to regulated OHW, as discussed in *Section 2.5.8* on *Annealing*).

However, sometimes a chemical reaction can also bring on a similar pink colour. A good example is the common "pickling" process, whereby copper immersed in a bath of strong acid can remove impurities from its surface (including stains, scale, etc), leaving the copper surface a fairly uniform dull pink colour.

Unfortunately, it's sometimes quite difficult to discern if a pink coloured portion of copper wire in the field is caused by annealing, or if it's by some other means, and the natural response is to remove and renew a portion of the wire – be it catenary or contact wire.

Unfortunately, the action of inserting a new portion of wire involves installing 2 splices, which then need to be maintained into the future, and they become potential weak spots in the OHW. And in the case of the contact wire, it may lead to some small arcing with fast pantographs, even if the splices are installed perfectly (e.g. due to their added weight).

Refer to *Figure 569*, which shows portions of a catenary wire coloured pink, next to a relatively new (and unaffected) catenary or auxiliary feeder wire, located under a road overline bridge. Apparently, the affected catenary wire had pink in a number of small patches when under the bridge, but the wire seemed quite normal outside the bridge. The contact wires underneath this catenary also seemed to be the normal copper colour.

So, was the pink catenary wire *annealed*?

Figure 569 - Discoloured (pink) copper may not always be annealed

We were assured there were no obvious signs of other damage, and no logical reason why this area should have locally overheated. It just looked genuinely *annealed*.

To my way of thinking, the most likely cause was chemical attack, because the pink colour only occurred in small patches next to areas that seemed unaffected, and the wire was fine elsewhere outside the bridge.

By its very nature, copper that's annealed due to overheating (by passing too much current for prolonged periods for instance) should show up over a significant length and not just in small patches.

The annealing should have been caused by something fairly obvious. For example:

- A diesel train parked under the bridge with its exhaust stack heating the OHW, but then the contact wires are much more likely to be affected (because they're lower and thus closer to the exhaust). There was no such sign of damage to the contacts. And this situation is unlikely anyhow, as discussed in *Section 5.5.3.4*, *Temperature*.
- Maybe too much current passing in the catenary wire. However, this would have likely affected the catenary wire for many hundreds of metres, not just in patches.
- A pantograph problem causing too much current to flow locally. There was no sign of this and no report of any such damage. And again, it should be the contact wire to suffer before affecting the catenary wire.
- A high-resistance connection to a clamp. This could result in localised overheating and annealing, but there were no clamps here.

There have been cases over the years of trucks spilling chemicals onto the road passing over the OHW, and the chemicals eventually leaching into the bridgework and onto the track. A likely culprit could also be a car or truck accident on the bridge causing battery (sulphuric) acid to spill onto the road. Even when diluted, this acid has the ability to pickle copper to a pink colour (however if left long enough, the colour turns blue = copper sulphate).

See *Figure 570* for another example, and notice the proximity of the joins in the segmented concrete cross-beams above the wire. They seem to be ideal seepage points for leaking chemicals in small areas, e.g. sulphuric acid from car batteries? And the acid would wick spirally along the catenary strands for a short distance, consistent with this photo.

Figure 570 - Discoloured (pink) Catenary under a bridge

Another point is that, if the wire was truly annealed, it would have stretched immediately and shown obvious signs of doing so. This particular catenary wire is regulated and with a huge 30kN (3 tonnes) of tension, so weakening of a number of annealed strands would likely cause the wire to stretch at this point and its diameter to then reduce (which could then lead to overstressing the wire). There were no such signs of stretching. Measuring the wire diameter and comparing it to the wire further away may prove helpful in this regard.

As I understand it, there was no easy test that could be readily performed in the field to identify bone fide *annealed* copper. Maybe a simple "Litmus" test could help detect the presence of any acid?

Any removal of wire would be an unfortunate outcome, as the additional pair of splices needed to repair the wire then become an item to be maintained into the future.

If it was a chemical reaction, then one attitude might be that the catenary wire should be removed in this area anyway, in order to get rid of the possibility of any remaining chemical residue trapped among the internal strands causing a problem in future. (Not sure what problem that would be though.)

On the other hand, if it's not annealed and the portion of affected wire is not removed but has the pink colour remaining, then the *perception* by others of it possibly being annealed may also be an ongoing issue that would need to be managed into the future. Maybe if this is the case, the wire should be cleaned (soaked) with a soapy rag to help remove any chemicals, then cleaned with a wire brush (or the like) to show the copper colour again.

Ultimately, a "standards" policy needs to provide clear instructions and a uniform approach when dealing with these unusual situations.

5.1.15 Robustness

One fundamental necessity of the OHW system is that it be "robust", to take the sort of punishment that's often dished up when the equipment is transported to site and installed, and later on when it's maintained.

Treading on the components, tossing items to the ground, etc. seems to be the way these items are sometimes treated during construction, and for the most part the equipment copes well with this punishment. Indeed, most of the equipment has been "overdesigned" (for want of a better term) over the years to withstand the punishment in this environment, which is often difficult to effectively control all the time.

However, this also means that the equipment is more likely to last a very long time, and with good reliability a consequence. And it is testament that the old fixed-anchored OHW equipment is often still in reasonable condition when finally pulled down, even after 60 years or so of good service.

Unfortunately, vandals add another unpredictable dimension to this, and no high-voltage insulator in the world can survive an attack with a rifle. But the robust nature of most OHW equipment ensures that even vandals need to try hard to achieve their quest for maximum destruction.

5.1.16 Materials

For Sydney's 1500V dc OHW System, various decisions were made in the past to help ensure a *reliable* supply to electric trains (with generally good results). Just a few comments here.

As mentioned in *Chapter 2*, the principal components in the OHW system are the *conductors* (for transferring electrical energy from substations to trains) and the *insulators* (which allow the conductors to be safely operated at 1500 volts). But for any mechanical system like this, there need to be clamps to connect various conductors together, strong structures to hold the wires in place above a track, and fasteners to connect structural parts and others together.

The materials for these aspects need to be appropriate for them to function correctly. So, below I've included something on the *materials* used for the main functional aspects of the OHW system, namely: *Conductors*, *Insulators*, *Clamps*, *Structural Elements* and *Fasteners*.

Refer to Standard EP-08000013-SP, "Overhead Wiring Fittings and Materials" for further details on materials.

Note:

In about 2013, I understand that the Materials Engineer in the Electrical Design Office of Sydney Trains was trained in the use of an *X-ray spectrometer analyser*. This hand-held instrument can detect the atomic composition of various metals, etc., and display both the chemical composition and its colloquial name (if appropriate). For example, the instrument can determine the composition of copper-alloyed OHW fittings, giving their relative % of copper, zinc, tin, silver, cadmium, etc., and displaying for instance "Gunmetal" and its grade.

This is an important tool for the Material Engineer, to allow him/her to confirm the integrity of certain critical OHW materials that are supplied. Of special note are those components called to have low electrical resistivity (for passing heavy currents), and for those that are expected to undergo high mechanical stresses in the OHW system.

5.1.16.1 Conductors

Copper is by far the preferred metal to use as a conductor for the heavy dc currents in Sydney's OHW system.

Steel has been used in the catenary in certain circumstances early on (although not necessarily as a conductor, only to support the copper contact wire below it).

Aluminium is not used at all as a heavy-current conductor in the OHW system.

Table 48 below shows a comparison of some important characteristics of these 3 metals, that relate in some way to their usefulness as OHW dc conductors. The subheadings below further describe *copper* (good) and *aluminium* (not so good for dc) only.

Characteristic	Copper	Steel	(Relative to Copper)	Aluminium	(Relative to Copper)
Density (g/cm³)	**8.9**	**7.8**	12% less	**2.7**	70% less
Electrical Resistivity [1] (Ω-m)	**$17x10^{-9}$**	**$170x10^{-9}$**	900% more	**$28x10^{-9}$**	65% more
Thermal Expansion (per °C)	**$17x10^{-6}$**	**$13x10^{-6}$**	24% less	**$24x10^{-6}$**	41% less

[1] – at 20°C (approx. value for carbon steel)

Table 48 - OHW conductor metal characteristics

COPPER CONDUCTORS

Copper is more than 3 times heavier than aluminium (as per the above table). This brings disadvantages, but it can also be helpful to have this extra weight in certain situations (e.g. when you want the catenary to sag as much as possible when approaching a low overline bridge, to pass under it).

Copper is about 65% more conductive than aluminium (per table). A good thing.

Unlike aluminium, copper does not corrode rapidly. If and when it does corrode, it tends to develop a fairly harmless green copper oxide coating (often taking many decades to form naturally). For example, the green coloured copper catenary wire taken down from the OHW on Sydney Harbour Bridge in about 2010, revealed that the green oxide coating was very thin and the copper remained mostly intact after about 80 years of service.

Making a good low-resistance connection to copper is relatively easy to achieve, and it can make for an extremely reliable connection over time, even when routinely cycling from zero to thousands of amps dc as trains pass through.

While it is more expensive than aluminium, copper brings with it many benefits that, in the end, help maintain the high reliability of the OHW system.

Copper is a relatively soft metal in its normal annealed state. However, when it's hard-drawn through successive dies of special shape, it becomes incredibly strong in tension, bending and torsion. It then becomes ideal for use as an OHW catenary or contact wire, able to undergo relatively high mechanical tensions (which is done to promote good dynamic performance interfacing pantographs on fast trains). See also *Section 3.1.0.5*, *Hard Drawn Copper*.

To improve the mechanical tension and wear resistance properties of the copper contact wires, there are a few copper alloys available, including cadmium-copper (used in fixed-anchored OHW since the early days, but now no longer manufactured) and tin-copper (which is used as its replacement). The disadvantage of these alloys is the increased electrical resistance (compared to pure copper). This means slightly more wasted ongoing energy into the future, and the added circuit resistance needs to be checked out for the DCCB protection system. Silver-copper is an alternative that has good conductivity, but it's not used in Sydney's system as yet (that I'm aware of anyway).

The unfortunate thing with copper is its $ value and the resulting probability of it being stolen whenever the opportunity is presented. See *Section 5.1.27*.

In Sydney's OHW system, copper is used for:
catenary wire, contact wire, in-span feeders, droppers, feeder cables, feeder plates (for cable-to-aerial feeder termination), etc.

Creep

An added advantage of alloying the copper contact wire with cadmium or tin, is a reduced tendency for the wire to "creep" over time (when compared to pure hard-drawn copper).

Creep is the gradual "flow" of the metal when it's under continual high mechanical force – be it in tension or in compression. (*Aside:* Glass can also creep over time, and as a student I was told that some of the original huge external glass display panels in old department stores, such as David Jones in Sydney CBD, are marginally thicker at the bottom than they are at the top, due to extremely slow flow of glass under gravity over many, many decades.)

It seems that a multi-stranded conductor (such as the catenary) creeps less than a single solid conductor (contact wire). This may have something to do with the hard-drawing process as the strand thickness is reduced in successively smaller dies. My understanding is that a far greater proportion of the cross-sectional area in a small wire is more effectively hard drawn to its core, and so has greater ultimate tensile stress. Put another way, it may be that a large solid hard-drawn copper conductor (i.e. contact wire) is less hard-drawn in its core than towards the outside, due to the nature of the drawing process through dies to its final size. So, it could be that this slightly softer portion near the centre is what allows any further creep to occur. If this is so, it would continue to harden over time in the process (albeit getting marginally thinner too). But all this is only my impression of what happens.

When constructing new OHW, the process of over-tensioning the wires (both catenary and contact) for a few hours before final adjustments, is aimed at trying to remove most of the initial wire stretch: from the *strands settling into their lay* (catenary), and also to remove most of the initial *creep* of the copper wires (catenary and contact).

An unusual situation that involves contact wire creep happened on the Gosford to Newcastle Electrification Project installed in the early 1980s. The project resulted in a regulated single 193mm² *hard-drawn copper* contact wire being installed throughout (under a relatively low

16.5kN constant tension). This wire has tended to stretch more than anywhere else in the network, and apparently it continued for a long time, even to today (although to a seemingly less degree). This means the tension regulators needed to be adjusted every now and then so that the weights didn't bottom out, and the tension regulator equalizer bar (that apportions tension to both catenary and contact wires equally) needed correcting too. I'm not sure if anyone determined the exact cause. See *Section 4.2.2*, *Conductors* for more on this peculiarity.

ALUMINIUM CONDUCTORS

The use of aluminium in any part of the dc OHW system seems to have been discouraged since the early days of electrification.

As I understand it, there was uncertainty whether it would reliably perform over the years when routinely carrying heavy dc current and in a cyclic pattern as the trains pass through. This may be due to its instability, to corrosion, or because of its chemical reactivity – I'm not sure. Or maybe it's due to the tendency, when cleaned in preparation for an electrical connection, to quickly revert to aluminium oxide which is an insulator – the opposite of what's needed. Or maybe it didn't have the strength to be tensioned enough to achieve the reasonably tight sags (*T/w*) that was needed for practical use above a train? Or the wire cross-sectional area needed for supplying the heavy dc currents was practically too large. Or it could be a combination of the above – don't know.

So, rather than accept the risk, the policy was to ban the use of aluminium as a conductor, or in any situation that attaches to a conductor and carries heavy dc current, on the +1500V side.

A notable exception to this rule is some proprietary equipment, such as the Type 6 section insulator which has an aluminium body. But even this equipment has special provisions to prevent dc current passing through it, i.e. insulation in the guy wires supporting it from the catenary wire, to prevent current feed from catenary to contact through the aluminium body. If you look back at *Figure 406* you can also see the type of damage aluminium can suffer over time (although caused by nearby repeated arcing in this case). Indeed, bare aluminium located near the coastline can rapidly corrode from salt in the atmosphere, forming a white powdery corroded surface.

To make a good, low resistance electrical connection to aluminium, both parts must be properly cleaned, and any clamp connection has to apply continual high pressure to the contacting surfaces. This is because the OHW conductors and their connectors need to be capable of carrying thousands of amps, and any significant resistance in the connection can readily result in overheating and possible failure in time.

As mentioned above, the problem with aluminium is that, as soon as you clean the surface (with abrasion, etc.), an oxide layer can quickly develop on the surface. Aluminium oxide is non-conductive, and it is also very hard (depending on its thickness). Both these aspects bring into question how effective and reliable any connections can be made in the field – *in every single instance and by all overhead lineworkers performing such work*. It might be that this last point has (at least in part) was a significant driver for the policy of not using aluminium in the 1500V dc OHW.

These days there are a number of proprietary products (compounds) that can be applied to the aluminium after cleaning its surface, to help prevent the oxide from forming. Sometimes there are particles imbedded in the compound to help in the conduction process too. So, getting a reliable low-resistance connection may be easier to achieve these days, but somehow this situation would need to be controlled, otherwise the reliability of the OHW system may suffer (and maybe when you least expect it to).

It is noted that aluminium is used extensively in high voltage ac systems, including in traction systems. Sydney's traction substations use aluminium in the various 33kV, 66kV & 132kV

HV busbar configurations on the ac side, however I think copper is still only used on the 1500V dc side. And of course, aluminium is used in the HV aerial lines that interconnect the substations.

5.1.16.2 1500V Insulators

See also *Section 2.9* for more details.

Refer to the following Standards:

- EP-08000019-SP, "Performance Specification for Overhead Wiring Post Type Insulator Units".
- EP-08000020-SP, "Performance Specification for Overhead Wiring String Insulator Set".
- EP-08000021-SP, "Insulator Type Tests – DC Power Arc Withstanding".

PORCELAIN

Since the early days of electrification and until the late 1970s, porcelain was the main insulation medium for 1500V.

Current OHW insulators using this material include fittings 453/13, 453/14, 453/15. The older post type insulator – fitting 452 – also used porcelain, and these robust units are still to be seen everywhere throughout the electrified network. The colour of the porcelain is either dark brown (older) or light grey (more recent).

Porcelain seems to cope well with compression and torsional forces, and to a lesser degree tension and bending forces (but this can depend, to a degree, on the insulator design itself).

In a termination or suspension insulator which is required to hold lots of mechanical *tension*, the insulator's design most often has the crucial part of porcelain placed in *compression* (to take advantage of its huge compressive strength), even though the overall insulator is in tension. Examples include fittings 453/12 (termination insulator), 453/13 (suspension insulator) and 452 (ceramic post type insulator).

Porcelain has stood the test of time from the early days of electrical awareness, however lately its presence has come under pressure from alternative insulating materials which offer various improvements – see below.

There are a few disadvantages to porcelain insulators, including:

- Porcelain has a tendency to chip if struck, which can result in razor-sharp edges that can readily cut skin.
- Accelerated corrosion can occur where any dc leakage current (distributed across the polluted surface of the porcelain insulation), exits the metal that's energized at +1500V. If that metal is the small diameter (13mm or 19mm) steel tongue, and it's on the live side, this offers a far worse corrosion outcome than the metal on the more substantial steel cap at the other end of the insulator. In this regard, a zinc sleeve is installed on the tongue, to act as a sacrificial anode, so as to help extend the life of the insulator. See zinc sleeve in *Figure 571* (from drawing EL0012109).
- Any porcelain cracks that extend into the core of the insulation may lead to puncture

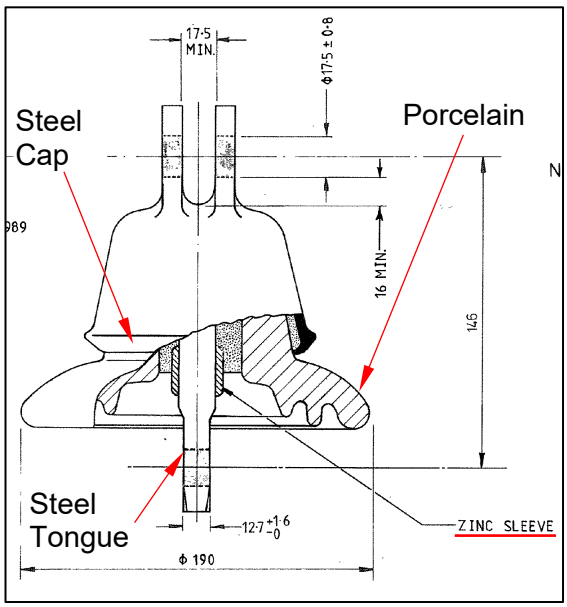


Figure 571 - Zinc Sleeve in porcelain Suspension Insulator 453/13

and/or excessive leakage currents. Tapping the porcelain can give an audible indication of this – if the tapping sound is dull (compared to a good insulator) then the crack likely penetrates into the core, and the insulator needs to be replaced.

- Vandals with rifles used to like using porcelain insulators for target practice.

See also *Section 2.9.1*.

FIBREGLASS ROD

It's likely that fibreglass insulators started to make their way into the Sydney's network in the late 1950s. I know they were used in the Compound OHW system inside some particularly tight tunnels. Here, "polymer bonded fibre glass rods" were used as pull-off arms (registering the catenary as well as the contact), solving a problem in what must have been a particularly tight and awkward situation. They are shown in *Figure 572*.

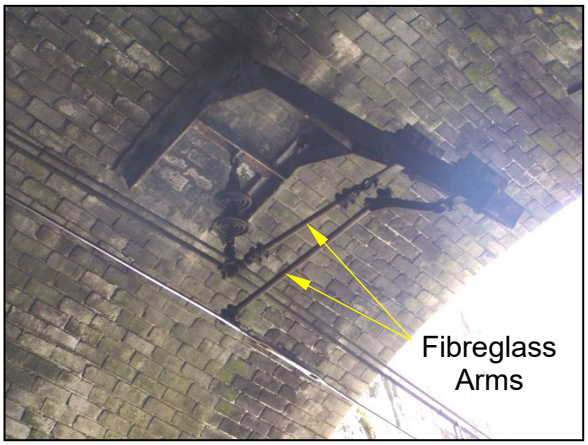


Figure 572 - Fibreglass Arms

More recently they have been used in large numbers primarily as termination insulators.

Fibreglass rod is exceptionally strong in tension, and these insulators are installed in the catenary and contact wires taking full tension (up to about 3 tonnes). The insulators are still in production today and being used throughout the system – refer to fittings 453/16 and 453/17 (the "K-Line" and "Reliable" insulators respectively).

These insulators are also much lighter than the equivalent twin porcelain insulators for terminating the various OHW conductors at anchor locations, making them easier to handle during installation.

The fibreglass rod is covered with a silicone compound to prevent water ingress. Unfortunately, water ingress is one of their failure modes (failure to insulate), and this can happen if the outer silicon layer is damaged (the fibreglass beneath this layer can act as a *wick* to draw moisture along the length of the rod and significantly reduce the insulation properties).

Their disadvantage tends to be their weak bending strength and more importantly their minimal torsional strength, and steps should be taken to ensure they do not experience either of these forces, especially during installation. Slender fibreglass insulators also have virtually no compressive strength (not that this is a problem at anchor locations).

See also *Section 2.9.2*.

CYCLOALIPHATIC RESIN

New technology in plastics resulted in this incredibly strong plastic resin (but the name is a bit of a mouthful).

Since about 1995, Sydney has used cycloaliphatic resin in the guise of a new post type insulator – fitting 452/10 – to replace the old porcelain post type insulator (fitting 452). They are dimensionally the same, however they come with threaded brass inserts (4 on each side), so they can only be used to connect to other fittings using set screws (i.e. no nuts). Note that this can be a limitation, and it sometimes traps people who think it's a direct replacement for the porcelain post type insulator. In some situations, it has required an intermediate adaptor plate. For example, you cannot use the shallow U-bolt fitting – "Insulator Bracket U-bolt"

(e.g. fitting 352) – because this fitting required nuts to be installed into the flange of the post type insulator, but the new insulator has no such flange.

There are many benefits to cycloaliphatic resin. These include:
lighter weight, cheaper to produce, can be made locally, and if the insulation chips, the resulting shards are not razor sharp (as they are for porcelain).

Apparently, the resin strength increases with age – at least that's what the manufacturer has said early on.

The insulated knuckle arrangement (fitting 41/42) uses a pair of Siemens insulators that are made from this (or similar) resin – see *Figure 117* further back.

So far, this material has not shown any significant problems.

See also *Section 2.9.3*.

PERMALI BEAM

Permali is a timber-based product that has been used in the electrical industry for a long time, mostly because of its good electrical resistivity (insulation) combined with its incredible strength. (Apparently there was very little else on offer with such advantageous traits.)

It's like plywood in that it's made up of a series of thin veneers of timber, with each layer placed at right-angles to the other (cross laminations). However, it is immersed in a special resin under pressure and this bonds the laminations together and makes it reasonably impervious to water ingress – initially at least. (If it's cut during the manufacture of a fitting, it has to be sealed again to prevent moisture being absorbed.) It's also dimensionally stable.

Permali is incredibly strong in tension, and has relatively good bending and torsional properties. It is also easy to machine to the required dimensions and has good thermal insulation properties.

It is relatively tolerant of any electrical flashovers along the beam, and can tolerate the extreme weathering of an outside environment (UV radiation) provided it is maintained properly.

It makes for an almost ideal insulating material for OHW, in situations such as:

- ***Type 5 section insulator***. Permali is used as the insulator beams in a Type 5 SI. In this configuration 2 such beams, spaced apart in parallel, take on the full applied tension of the contact wire (up to about 20kN or 2 tonnes). The beam is even more useful because the underside can come close to the carbon strips of passing pantographs or even touch them from time to time, and tolerate this. Refer back to *Figure 400* for instance.
- ***Insulated Knuckle***. Here the beam can be drilled to take the contact attachment clamps at both ends of the beam, placing these attachments at the required distance to suit the spacing of the contact wires. This can take place at a turnout. It has also been used in the old fixed-anchored OHW to separate the 2 wires within the overlap bay of a feeding overlap (airgap), to ensure that the wires of the 2 different electrical sections don't touch under extremely gusting winds.
- ***1500V Switches***. Permali has been used in part of the vertical operating rod which controls the opening and closing of the blade/s of a switch.
- ***Insulated Stop Beams***. These are simple beams installed horizontally under a bridge and above a catenary wire, and so positioned to prevent the catenary wire from touching or coming too close to the bridge (*Figure 189*).

One down side is that, over time and with much weathering and/or arcing, its surfaces can eventually become carbonised and porous, which can then retain moisture. This may cause some issues, especially if installed on a section insulator. For instance, the lower resistance caused by moisture trapped within the beam has sometimes led to false voltage readings of

de-energized OHW (with the other side alive) when testing dead prior to applying contact-to-rail connections.

They can sometimes be reconditioned by removing the damaged surface and painting (white?) to seal the surface again (provided there's suitable strength remaining in the beam).

See also *Section 2.9.4*.

5.1.16.3 Conductor Clamps

When a conductor (catenary or contact wire) needs to pass heavy current to another conductor, the connection needs to be made in a way that does not damage the conductors, particularly to their outer strands (if any).

Suitable "pads" are required in such a situation, to act as a passive interface that allows the heavy mechanical clamping forces needed to provide a low-resistance electrical connection, in order to pass large magnitude dc current (up to 1,000 amps or so) in the OHW system.

Typically, these clamping forces are applied by a stainless steel U-bolt.

To connect 2 catenary wires together, the whole assembly (*Figure 573*) consists of the following:

- A *saddle piece*, installed under the bent U-shape of the U-bolt, is typically made from gunmetal. It has a curved shape to match the U-bolt diameter (to bear its pressure), and a curved shape to match the diameter of the 1st conductor, so that the bearing pressure won't damage the outer strands.
- A *feeder pad*, usually made of hard copper, with curved contours to match the shape of both conductors being connected, again without causing damage to their outer strands. This part is where the majority of the current is intended to flow between the conductors.
- A *base*, typically made from gunmetal, with a curved shape to bear against the outer strands of the 2nd conductor, and with 2 holes that accept the legs of the U-bolt and allow the installed 2 nuts to tighten the whole assembly. The 2 nuts, with their fine-pitch metric thread, apply considerable force to clamp these 2 conductors, which can yield a low electrical resistance connection.
- A *U-bolt* with 2 nuts, washers and spring washers (all stainless steel), using fine pitch threads.

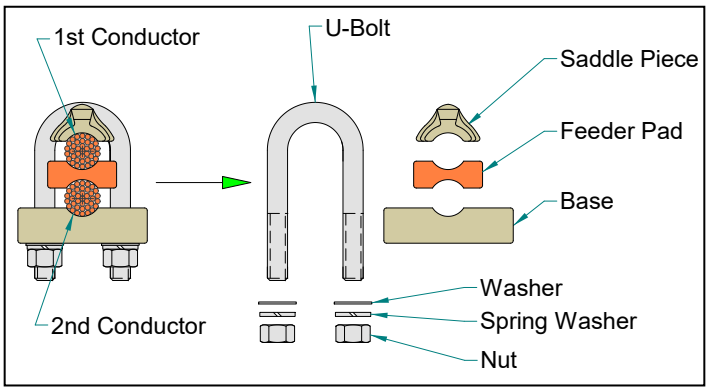


Figure 573 - Feeder Clamp

Note that the feeder pad sandwiched between the 2 conductors is shaped to either connect these conductors together:

- In parallel – a *parallel feeder clamp* (per *Figure 573*), or
- Perpendicular to each other – a *cross feeder clamp* (seen in *Figure 574*).

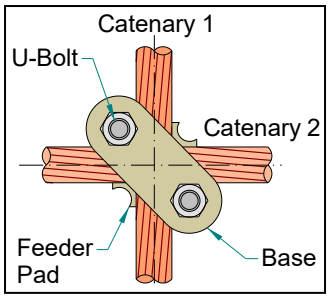


Figure 574 - Underside of Cross Feeder Clamp

GUNMETAL

This metal is an alloy comprising copper, tin and zinc, and it can be found in many fittings in Sydney's OHW system. It is relatively strong in tension and in compression, does not readily fracture under impact, and

offers a reasonably low electrical resistance when connected to copper wires. It can provide a relatively "soft" interface with copper wires, tolerating high compression forces quite well. Importantly, it does not corrode in the OHW system, so it can be readily cast or machined to shape without the need for any protective treatment.

Overall, gunmetal has proven to be quite a robust metal for use on the *live* side of OHW. To give an idea of the versatility and prevalence of this metal in the OHW, it's used in:

Catenary suspension envelopes (98/3)	Catenary saddle clamps (168/3)
Catenary termination (snail) clamps (281/3)	Catenary cross feeder clamps (54/38)
Catenary parallel feeder clamps (54/17)	Overline bridge catenary clamps (187/1)
Catenary-to-contact feeder clamp (55)	Contact half splice (511/19)
Catenary suspension (butterfly) clamp (296/1)	Contact full splice (462/8)
In-span feeder clamp on contact wire (56/14)	
10mm U-bolt "Crosby" clamp (e.g. 463/21)	Contact-only support bracket (531/15)

Some of the various fittings that use gunmetal on the *live* side of OHW are in *Figure 575*.

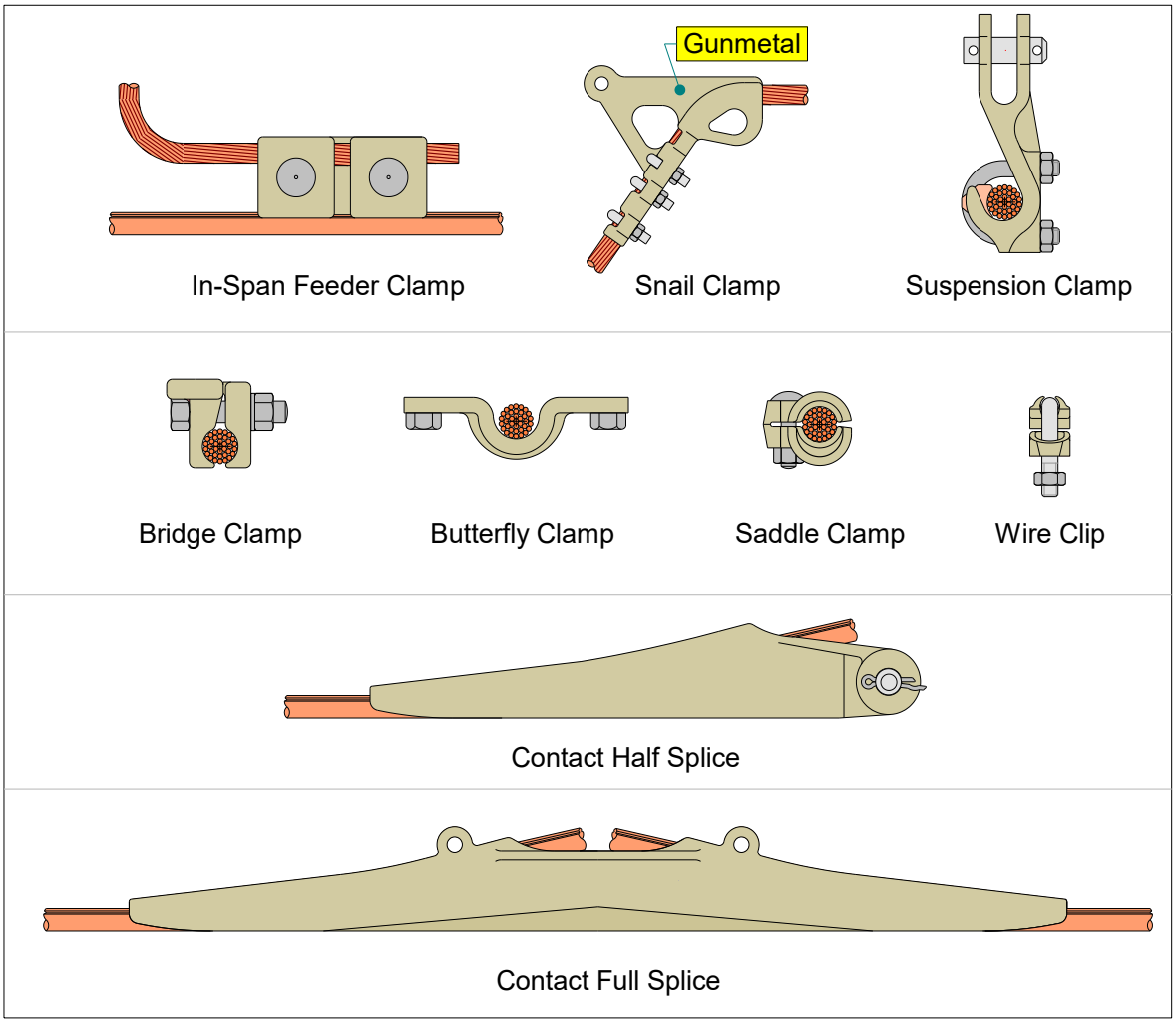


Figure 575 - Some examples of the use of Gunmetal in various "live" OHW fittings

5.1.16.4 Structural Elements

STEEL

Almost all OHW equipment that requires some significant strength, uses mild steel (that's been hot-dip galvanised to protect it from corrosion) – abbreviated to "MSG".

Some parts, such as OHW masts installed in the ground, are required to be relatively stiff as well as strong. The rigidity of a structure helps limit its deflection when loaded with OHW and its supporting cantilever. But the structure must also endure wind gusts without causing too much *change in contact stagger* – see *Section 6.3.2.2*, *Pantograph Security* for more.

There's a lot of steel on the "dead" side of the OHW, including the support structures, OHW cantilever frames, switch frames, gallows fittings, etc.

But even on the "live" side, some steelwork exists, including almost all pull-off arms. These arms are required to have high strength to register the contact wire in position with large radial + wind loads, and a great deal of stiffness so the arm doesn't change shape too much under these loads (with the wind load adding and subtracting from the radial load), and they should be relatively lightweight, to minimise any "hard spot" as seen by passing pantographs.

Steel chain links (Fitting 144/4) have also been used on the live side since the 1990s, essentially to replace the (relatively expensive) copper span wires in certain situations (e.g. to connect from insulator to the pull-off arm/s). One benefit of using chain links is that you can see from the ground whether the correct number of links is used in a pull-off arrangement (compared with the output of CCALC program), whereas it's impossible to check the length of a span wire from the ground. The chain links are also easier to adjust, giving ±50mm incremental stagger change.

The key to using MSG parts on the live side, is to avoid placing them in a path that causes them to conduct heavy dc currents – they are not suitable for this.

It's also fortunate that steel is relatively cheap and readily available in Sydney (since Australia has vast amount of iron ore and still has steelworks in operation).

STAINLESS STEEL

Stainless steel has had only limited application in large structural items.

It's more used in smaller parts on the live side of the OHW. This includes the light tubular SS twin contact pull-off arms used in the Liverpool to Glenlee Electrification Project. And the 150mm cast SS links (Fittings 312/14 and 312/15 – the "doggy bone" spreaders) for connecting between a pair of side-strain insulators, etc.

SS items have only been used in situations that do not cause them to carry significant dc current (i.e. leakage currents less than milliamps are probably OK for the long term).

5.1.16.5 Fasteners

Metals used for holding items together (including pins) seem to be limited to only a few types.

STEEL

Joining the various structural items together that require significant strength, has been limited to fasteners made from steel.

Mild steel galvanised (MSG) provides a reasonable degree of compressive and shear strength.

High tensile bolts are used where additional strength is required, such as in support structures, and as called up by the relevant design drawing/s.

STAINLESS STEEL

Stainless steel comes in quite a number of different grades (expressed as a number), offering differing properties to help match the circumstance, including:

degree of corrosion resistance, hardness, tensile strength, magnetic properties (or not), ease of machining or casting, etc.

The use of stainless steel (SS) for *fasteners* seems to apply more to equipment on the live side of the OHW system. This includes the multitude of U-bolt fasteners used in various conductor clamps, and bolts and set screws for connecting steel parts to insulators and the like, etc.

The grade of stainless steel is critically important to its use as a reliable fastener. The grade is called up in the relevant design drawing/s.

The beauty of stainless steel is that it doesn't corrode. It's particularly useful when connecting dissimilar metals together (*Section 5.1.11*). So, provided the correct grade has been used, and it doesn't carry any significant dc current, it has proven to be a reliable metal with relatively high tensile and shear strength, and requiring virtually no maintenance over the long haul.

It seems that the closer any OHW equipment is located near the pantograph path, the less likely that parts are fastened using MSG – SS is by far the preferred metal in this critical area.

If there is a down side to using stainless steel, it would be the tendency for it to develop *Galling* during the initial fastening process, or later on when undoing the fastener – refer to *Section 5.1.22.3* for more details on this surprising phenomenon.

There's more to be said on SS fasteners further on in *Section 5.1.22.1*.

HARDENED COPPER

Because of its relatively limited strength, there have been only a few early situations where copper was used as a fastener. (It was more likely used in the absence of other more suitable metals that we now have today.)

I am aware of some old parts that used a copper-based alloy for bolts, to connect them to the conductors in some fashion. Copper on copper is a good interface (in the absence of refined stainless steel technology).

Hardened copper had been used for rivets in the Type 6 section insulators, to fasten the height-adjusting steel angles to the long copper side runners. In such cases where not a lot of strength is needed, the head of the copper rivet can be hammered into a countersunk hole in steel (for instance). The head can be ground down to being almost flush with the steel surface, so as to not become a snag point to passing pantographs or maintenance workers, etc. Fastening a copper runner to galvanised steel using copper rivets was probably a minimum risk approach back then.

5.1.17 Friction & Lubrication

The OHW is an electrical and mechanical system. On the mechanical side, there are various parts that move relative to other parts. More often than not this movement is rotational (e.g. the taper roller bearings in a weight tension regulator pulley).

Any movement of parts that are highly loaded should normally require some degree of lubrication to help cope with the corresponding friction. However, for the OHW system this is not always the case.

Lubrication is typically applied to moving parts, both to *reduce frictional forces* on the contacting parts and to *minimise their wear* over time. In the case of the pulley bearings mentioned above, any frictional loss in their 6 roller bearings (3 pulleys) causes a deviation from the important constant regulated tension being applied to the bays of OHW conductors. Obviously, with less friction, the tension in the OHW can be maintained closer to the ideal design value, which is a desirable outcome.

The problem with lubricating various parts of the OHW is that this equipment is mostly installed in the outside environment, and therefore is subjected to various deleterious effects on any lubricating oil or grease (that is, unless the lubricant is effectively sealed in some manner from the outside environment).

Wind can blow sand or dust grit onto the exposed lubricant and adhere to it. Over time, these foreign abrasive particles can form a type of "grinding paste", and make their way into the area of action within the lubricant, which can ultimately lead to much increased friction and wear on the parts. This is the exact opposite of what's intended (the lubricant is meant to *reduce* friction). Even where the OHW is installed inside tunnels, it can be subjected to brake dust from trains, and dust from the ground stirred up by trains passing through at speed, etc.

Unless special measures are taken, over time the lubricant can also dry up or otherwise change its lubricating properties.

Most of the regulated support & registration components that see some relative movement when mechanically loaded, do not rely on any lubrication. This is because the rotational movement is often relatively small and can take hours before needing to move even a bit. In addition, the mating metals have proven to be able to cope well with this type of movement without wearing too much, even after decades of use.

There are many examples of this rotational movement in the various support & registration arrangements, especially the cantilevers.

Example 1:

The vertical galvanised steel tube at the end of a pull-off arm that connects over the 17mm diameter vertical stem of the stainless steel contact swivel clamp (fitting 61/2).

In a regulated system, this often highly-loaded connection sees relative rotational movement of only a few degrees when the contact wire moves backward & forward longitudinally with temperature changes throughout each day. The interface between stainless steel and zinc coated steel tube has worked well without the need for any lubrication, over many decades of operation.

Unfortunately, a grease applied in this case may cause any foreign particles to adhere and then abrade the mating metals. And any grease in such a situation could also be quite messy to deal with when it comes to changing out parts during hands-on maintenance.

Example 2:

The twin suspension insulator arrangement (fitting 241/9) connects to the galvanised steel *guitar head* fitting of a cantilever using a shackle.

The 16mm stainless steel pin of the shackle is installed into 1 of the 3 holes in the guitar head, and permits the highly-loaded suspension insulator string to swing under the combined influence of catenary radial load and weight load. If the catenary tension changes or, more importantly, if there's gusting wind, this can cause relative rotational movement, but again no lubricant is needed here for the same reason as above.

Example 3:

The 33mm diameter stainless steel "Jib Pin" (fitting 948/2) that connects the bottom of the cantilever pipe to the galvanised steel mast attachment bracket – *Figure 576*.

This situation places a huge downward thrust load from the pipe to the bracket. At the bottom of the pipe is a thick galvanised steel washer with two 15% glass-filled PTFE washers under it (one white and one blue), to help spread the compressive vertical load onto the horizontal surface of the bracket as the pipe rotates about the pin axis.

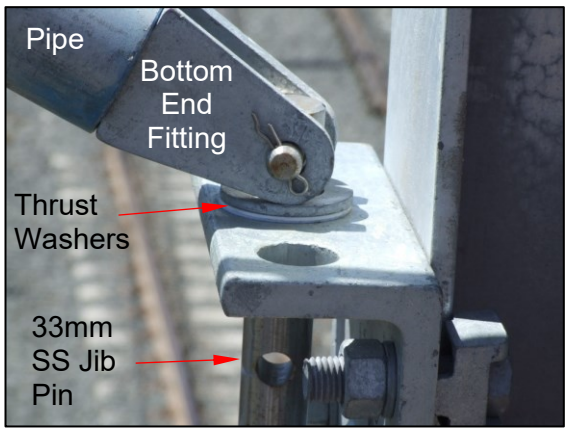


Figure 576 - Jib Bottom End Bearing

The 33mm SS pin also bears against the matching holes in the jib support bracket attached to the mast – stainless steel against thick zinc galvanising.

Even with both these bearing loads, no grease is used – it's totally dry (as seen in the photo).

It seems that the thick galvanised coating on a steel component offers a good interface to the smooth surface of a stainless steel pin, so rotational movement seems to not need any grease. Even over much time, there appears to be no evidence of the zinc coating wearing to such an extent as to cause the steel to rust in any significant way. (You'd see any rust by the brown stains leaching from this connection onto the lower fitting, but there's usually none.)

Importantly, without the grease there's no reason for any airborne grit to collect and stick, and start grinding the connecting surfaces.

There are several benefits resulting from no lubrication being needed in these situations:

- Saving $.
- No need for messy lubrication when first installed.
- No need to periodically inspect and/or clean and relubricate, which could sometimes be difficult to do when already installed.
- If grease isn't there, then it can't transfer onto workers' clothing.
- Less chance of dirt, etc. to be trapped and then abrade the moving parts – longer life.

However, it is imperative that the few OHW items that *do* require lubrication (such as the critical weight tensioner pulleys), *are* properly maintained over their lifetime.

Note that over prolonged periods, UV radiation can damage plastics used as a barrier to seal in the grease, such as in the case of the black plastic seals used on tension regulator pulley bearings. See *Section 3.4.2.3, Pulleys*. These seals tend to form cracks over time (decades), which then allows moisture into the bearings, resulting in corrosion and causing the bearings to eventually seize. But the special UV shields can help in this regard.

It is helpful to apply grease to stainless steel threads before fastening, in an attempt to prevent *galling* (refer to *Section 5.1.22.3* further on for what this means).

Various feeder clamps require grease to be applied to the cleaned contacting surfaces before being assembled and tightened. Although grease is not conductive, it does help to prevent oxidation and corrosion, which can occur between dissimilar metals.

It may be useful to cite the 2011 drawing for some of the 54/- series of cross feeder clamps (drawing EL0023854), with Note 3 stating, "Surfaces of components such as pad, saddle and clamp that make contact with the wires should be applied with a thin film of AP3 grease".

5.1.18 Insulation to Minimise Leakage Currents

Various types of insulating materials have been used in the past in a deliberate attempt to prevent even small levels of dc current from taking unwanted paths. This has usually been done to protect or extend the life of some component which might otherwise be affected by passing these small currents over a period of time. For example, apparently some grades of stainless steel do not tolerate dc currents that well, and may become brittle over time (and snap under load). So, great care is needed with 16mm or 19mm SS pins. (See also *Section 2.5.9* and *Section 2.9*.)

This is nothing to do with the primary insulation, which can have its own leakage current problems across the insulation surface (e.g. due to pollution build-up).

The 2 main situations where this additional low-level insulation is needed is:

- In the *1500V "*Conductor*" system*, where all the conductive items are at 1500V. In this case, the properties of any low-level insulating material are not that critical – it only needs to cope with less than about 1 volt across the insulation (but both sides are at 1500V). E.g. the *loop strain insulator* installed in a dropper wire supporting a cross-span wire – see *Figure 577* and *Section 5.1.18.1* below.
- On the *traction return* ("dead") side, in the case of some *bonding* schemes. Refer also to *Section 3.12*, *(Bonding)*.

In either case, the insulating materials can be similar, but this depends on any strength requirements as well.

The evolution of plastics, especially in more recent times, has led to an expansive array of materials that could be used in the OHW system. In addition to providing the necessary electrical insulating properties, various plastics can offer different physical properties that can be beneficial in certain circumstances. For example, some situations might require the material to have excellent compressive strength (such as in the case of providing secondary insulation when connecting a drop vertical to a portal bridge, with the insulation pad inserted between both).

There will likely be benefits in standardising on one or only a few types of plastics out of the range of possibilities, depending on the specific type of situation.

Most materials need to have a certain resistance to UV radiation in the outside environment.

However, there are also some older insulation technologies that might still have a place in the OHW system, including porcelain ceramic.

5.1.18.1 Ceramic

Loop strain insulators are small ceramic insulators that are commonly used in support & registration cross-span situations – *Figure 577*. Here, this insulator is used in line with vertical solid copper wire, that then holds the cross-span wire at a certain level as it crosses the various tracks. Their use is shown way back in *Figure 185*. The 2 loops are configured to put compressive load onto the ceramic.

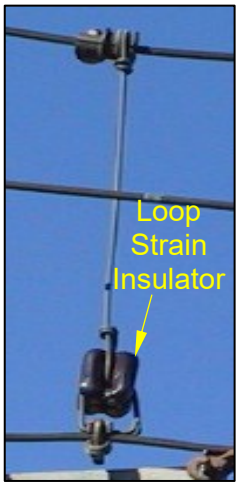


Figure 577 - "Buller" Insulator

In this situation, the insulation is there to prevent any current taking an alternate path – through the solid copper wire – from catenary to contact wire in this S&R arrangement (after all, that's what the in-span feeders in the adjacent bays are meant to do).

Unfortunately, ceramic is brittle and is quite susceptible to being damaged. Any broken-off shards can have razor-sharp edges and can easily cause injury (such as cuts to the skin).

5.1.18.2 Acetal Resin

The most common acetal resin in OHW use has been "Delrin". It has been used since the early 1980s in all sorts of applications, including the following:

- The *delrin bar twin contact dropper arrangement* (fitting 95/21), which supports the twin contact wires from a single catenary wire, and spaces the twin wires 50mm apart throughout the bay. (*Figure 77* much further back).
- *Catenary rollers*, to help guide the catenary wire under overline bridges (back in *Figure 252*).
- *Type 6 SI guy insulators* (on each of the 2 guy wires) for supporting & aligning the aluminium body of the Type 6 section insulator from the catenary.
- Various *insulating ferrules* used in bonding schemes (see photos below).

Over the decades, *Delrin* has proven to be a reliable product because it has good insulation properties, is mechanically strong (for a plastic), it's easy to machine (drill or lathe) or cast to shape, provides low friction, operates under a wide temperature range (typically -40°C to 120°C), is wear resistant, is dimensionally stable and interfaces well with metal parts.

Another more recent acetal co-polymer is "Sustarin-C", which is similar to the above.

This robust plastic has been called up by Civil Design from the late 1990s for inclusion as insulating *pads* and *ferrules*, used for insulating drop verticals from the underside of steel portals and bridges, etc. (consistent with the needs of various OHW bonding schemes).

Refer to *Section 3.12.0.5*, *Levels of Insulation* for one of its uses in *Secondary Insulation* schemes.

With secondary insulation, insulating ferrules and associated insulating pads (see *Figure 578*) are often employed to provide a means of insulating a threaded bolt from a steel attachment plate. These ferrules usually consist of a circular collar with a flat disc at one end. The disc takes a steel washer (shown) to help spread the mechanical load as the bolt is tightened.

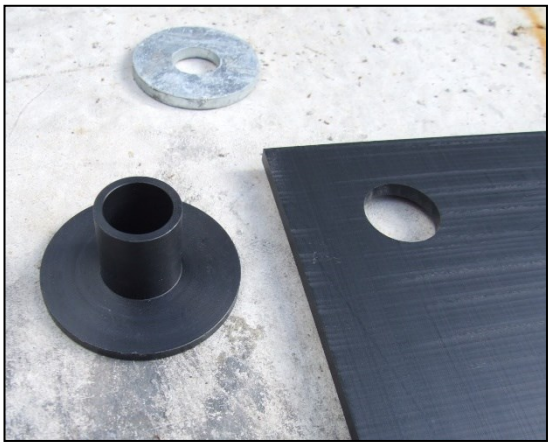


Figure 578 - Insulating Ferrule & Pad

Figure 579 is a typical application of insulating ferrules and pads, providing secondary insulation to a fixed mid-point location at Chatswood.

Figure 579 - Ferrules & pads providing secondary insulation

5.1.18.3 Nylon

Recently, a special "nylon" has been included into the OHW system.

One of the parts that uses this material is the *Insulated Dropper Sleeve* – fitting 95/31. This was designed to be retrofitted (clipped on) to the lower dropper loop where it interfaces with the upper loop, to prevent any current from micro-arcing and damaging the otherwise copper-to-copper interface (which had been a common problem). Refer back to *Figure 88*.

The actual material is "Amidene AM90/1 R01 Black", and is apparently quite suited to the harsh external environment of the OHW with high UV levels. (Word has it that the material is also used on car dashboards.)

5.1.18.4 Tufnol and Novasteen

"Tufnol" and "Novasteen" are the brand names of 2 commercial insulating materials that have, in the distant past, been preferred by Civil Design, when providing some insulation for various parts in bonding schemes.

These materials are made from multiple layers of phenol formaldehyde resin-impregnated cloth, to form a compressively strong material with reasonably good insulating properties. Within reason, they are relatively easy to cut to shape.

They have been used as insulating ferrules and pads, to isolate things like horizontal safety screens installed on overline bridges. In this situation they allow the screen to be spark-gap bonded to track without any electrical connection to the bridge steelwork (ideally).

The major drawback with using these materials is that, once cut to shape, they need to be varnished or otherwise sealed to prevent moisture wicking into the cloth and dramatically reducing their electrical insulating properties.

Note that, even if an item has been properly varnished, sometimes the amount of pressure applied in fastening the arrangement can tend to crush it slightly, which can partially destroy the seal and so allow moisture in. Medium voltage "megger" tests have demonstrated how quickly this material can deteriorate in the open (subjected to rainfall, etc.), with initial meg-ohm readings falling to only the tens of ohms (instead of millions of ohms), and often in unpredictable ways.

Their potential for *wicking* moisture (with corresponding uncertainty) tends to make them somewhat less reliable as an insulator for the long term, unless used in situations that always remain dry.

5.1.19 Strength & Safety Factors

As has been the case with most of the engineering world in the 1900s, the strength of OHW equipment has in the past been based on the notion of "safety factors", which generally apply to each component of the equipment and to the final assembled piece of equipment.

The safety factor (SF) is a number representing the level of additional strength that's needed above some determined maximum applied load level. As such, it is a ratio of some breaking load to the maximum anticipated load.

For example, a *3:1 SF* means that the strength of the situation is 3 times stronger than it needs to be. It seems that this is more commonly expressed as *a safety factor of 3*.

The additional margin of strength is needed to give some level of comfort that the situation will not fail. There are two sides to this that can cause failure: those coming from unanticipated *increases in applied loading* and /or those that result in a *reduction in the strength* of the item. Some examples include:

Increased load:

- Collision from an outside object (this depends on the degree and nature of added loading). E.g. a tree falling on the catenary wire, or a truck running into a mast.
- Wind speeds in excess of the maximum design wind speed (including any "gusting").
- Super-tensioning the catenary wire for a period of time after installation, then releasing it back to normal tension.
- Due to extremely cold temperatures, e.g. a high fixed-anchored contact tension if the ambient temperature falls below the minimum design temperature.

Reduced strength:

- Corrosion of part of the item.
- Mistreatment of items during transport or assembly.
- Any damage due to collision with another object.
- Fatigue.
- Lightning strike.
- UV damage over time in some plastics or rubber.

The safety factor used may vary depending on its relative criticality to the end system.

For OHW equipment the general safety factor has been 3:1, but other materials have required a higher strength (probably due to increased uncertainties):

- Metallic parts (general) – 3:1
- Metal castings – 4:1
- Plastics – 4:1
- Fibreglass – 4:1
- Copper conductors – 3:1
- Copper contact wire – Approx. 2:1 when it's worn down to "condemning size" and needs to be renewed (refer to the Standards for the most up-to-date information).

Note:

Refer to the Standard EP 08 00 00 13 SP, "Overhead Wiring Fittings and Materials" for the most up-to-date information in this regard.

With the aid of sophisticated computer programs these days, it seems the current engineering trend is to apply "limit state" design techniques (not safety factors). Apparently, this approach can better model the expected forces applied to the equipment, and in turn deliver a more realistic outcome in terms of the management of the equipment's ultimate strength and serviceability. However, I understand there is less margin for error with this approach, especially with the unforeseen events (but I may be wrong here).

5.1.20 Connecting Items Together

Although the OHW system is there to supply trains with electrical current at 1500 volts, it is very much a mechanical system, which is put together using a myriad of connecting parts, much like a "Meccano Set". As such, it's important that the various methods of joining the parts is done in a way that is cognisant of the actual application and any applied forces.

Fasteners join at least 2 parts together, and in a way that can usually allow for disconnection at some later stage.

Connected parts can be fastened using *nuts & bolts* which generally tighten items together. Alternatively, some parts can use *pins* for connection, which simply keeps the 2 (or more)

parts in alignment. Other parts can be held in place using clamping pressure, such as when using *cleats*. These methods are discussed in *Section 5.1.20.2* below.

There can be unusual forces on certain connected components that need special treatment. For example, *vibration* (e.g. caused by the interaction of train pantographs with the contact wire), used to be a common cause of certain conductor components becoming loose, eventually resulting in disconnection and damage to the OHW and /or train, and ultimately bringing trains to a halt until repairs were affected.

The various systems available for connecting items together are discussed below.

5.1.20.1 Fasteners

BOLTS & NUTS

By far the most popular types of fasteners used in the OHW system are bolts and nuts, which often including spring washers to help prevent a nut from coming loose (especially with vibration). See *Section 5.1.22* below for the importance of thread pitch in certain circumstances.

Holes should be well matched to the diameter of the bolt passing through, so as to not overstress the fastener (in shear).

Refer to *Figure 580*, which includes a bolt & nut on the left, and a set screw (with fully threaded shaft), nut spring washer & flat washer on the right.

Common thread sizes for OHW work include M10, M12, M16 and M20.

A flat washer is used to help spread the mechanical load onto the part being connected.

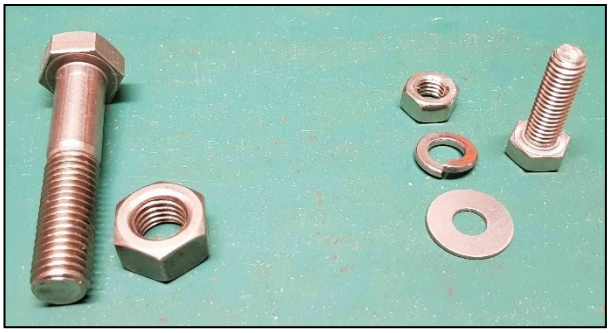


Figure 580 - Bolt (left) & Set Screw (right)

Spring washers, if used, are normally the type with a single helical loop, and with a barb at each end that tends to bite into the metal for added security. Any spring washers that have been flattened or have the barbs damaged or worn, should be tossed out.

Sometimes it is important to apply a certain bolt torque to an assembly, to ensure things don't come apart during service. A torque wrench is often prescribed in these situations.

The term "Snug Tight" sometimes crops up when fastening bolts, and I understand it's referenced when constructing OHW structures. The definition of snug tight varies, but according to AS4100 for Steel Structures, it used to be defined as the tightness attained by the full effort of a man using a standard "podger" spanner, or by a few impacts from an impact wrench. The intent is to apply a reasonable amount of tension to the bolt without going overboard. It may be that this is partly to allow the bolt to have sufficient reserve strength in case unintended overloading of the equipment occurs at some later stage. It may also be used to help preserve the item being fastened, such as if it has plastic resin parts in close proximity to its fastening mechanism, e.g. the brass inserts in 452/10 resin post type insulator (?).

However, the more precise method of applying tension in a fastener requires the use of a torque wrench, with specified torque settings for different sizes or applications of fasteners.

SET SCREWS

"Set screws" (right side of *Figure 580*) are another fastener that find applications in all sorts of equipment. A set screw is basically a bolt but with the thread covering almost the entire

length of the shaft. This is handy for fastening 2 thin pieces of metal together without worrying about running out of available thread (if using a bolt alternative).

Set screws are particularly suited for attaching an item to a threaded insert (or "socket"), such as the brass inserts embedded in resin found on the (now common) 452/10 post type insulator. See *Figure 581*.

Figure 581 - Set Screw into threaded socket

Again, the problem with using a bolt is that, if the limited external bolt thread runs out (and it's hidden from view so it's not obvious), then the bolt will jam against the insert, and there's a danger of damaging the threaded insert (or its cast resin connection, in the case of the insulator mentioned above). The only way to tell if things are okay is if the included spring washer is flattened and there are no gaps between mating parts. But even then, there can be uncertainty whether the bolt is tight because it's actually a solid connection or whether it's simply run out of thread and become jammed (without providing the necessary security).

When it comes to threaded sockets, the correct fastener *length* needs to be used (as called up by the relevant design drawing). Any mistaken use of a shorter fastener will not be evident as it's hidden from view, so it's important this this length be correct when first installing the fastener (lest it jeopardise the strength and longevity of the connected arrangement).

Of course, the eventual length of thread in contact with the internally threaded socket has to be sufficient for the applied load.

The tendency in design these days is to call up set screws wherever practical, then you don't need to think about the extent of thread in an application.

PIN CONNECTIONS

The use of pin connections has been quite successful in various types of OHW equipment over recent decades, including cantilever and tunnel cantilever designs where incremental adjustment is needed. They can provide convenient positional adjustments, by allowing the pin to be taken out and used in another hole located typically 50mm one way or the other. See *Section 5.1.21.1* below for more on the benefits of using pin connections.

A shackle uses a pin to connect a piece of equipment to a length of chain or span wire (with copper thimble interface for wire protection), or to the pin of other parts (such as a suspension insulator).

As mentioned previously, holes in the connecting plate/s should be well matched to the diameter of the bolt passing through, so as to not locally overstress the pin (in shear). Installing a 16mm pin in a 24mm hole for instance, would normally be frowned upon.

Typically, a 16mm pin would require a 17mm drilled hole (which also provides some allowance for zinc build-up in the hole when galvanised). Installing a 16mm pin in a 24mm hole for instance, would normally be frowned upon.

A "split pin" is usually installed at one or both ends of the main pin, in order to prevent the main pin from falling out. See *Figure 582*.

"Circlips" have also been used in some equipment to perform this function, although they have tended to be too fiddly to install by workers with gloved hands.

Sometimes a bolt (with a nut) is used as a pin connection, without the need for much tension in the bolt. For example, the Type 1 or 2 cantilevers (Mk-2 series) use 2 bolts to connect the pull-off external tube to the twin vertical plates. Here, there cannot be much tension in the

bolts because there's no solid steel to tighten the nuts against. See *Section 4.2.4*, *Support & Registration* for further details of this cantilever situation (*Figure 538*).

See also *Section 5.1.21.1*, *Hump-Back Split Pins* for more information.

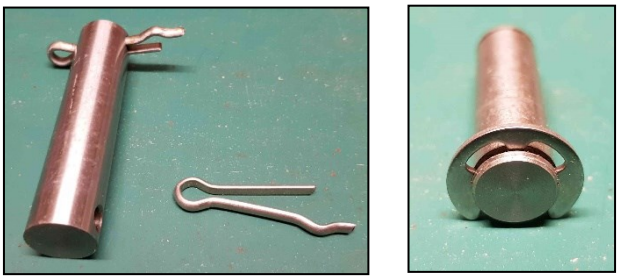


Figure 582 - Hump-Back Split Pin (left) & Circlip (right)

RIVETS

The use of rivets isn't all that common in OHW equipment. They found application in the Type 6 Section Insulator for securing the steel angle section to the copper side runners. Solid hard drawn copper (or alloy) rivets were used here (but these steel angle strengtheners are no longer needed).

The problem with rivets is that they need to be properly installed, because often they are located in places where vibrations are the norm. For instance, the above SI is shaken about to a small or large degree by each passing pantograph (depending on whether it's been properly aligned).

Pop rivets are sometimes used in sheet metal connections, such as for fastening signs to a post. But again, the need for these is rare in the OHW system.

If used, the preference is for rivets to be made from stainless steel, for obvious reasons.

SELF-TAPPING SCREWS

Self-tapping screws have an extremely coarse thread pitch. They are designed to make their own thread in the (softer) mating material as they are driven home.

Like rivets, these screws don't get used much in the OHW system, probably because their extremely coarse threads have a ready tendency to come loose with vibration.

If used, they would be mainly relegated to connecting thin sheets of metal together in unusual situations well away from the OHW conductors.

This might include fastening signs to equipment such as labelling the feeder number next to OHW switch operating handle mechanisms – maybe.

5.1.20.2 Types of Connections

HOLE CONNECTION

In order to make a connection using a bolt, set screw, pin or rivet, the holes in 2 (or more) parts need to align.

In the case of a bolt or set screw, the fastener passes through these aligned holes and is tightened to make a solid connection. The hole sizes need to be marginally larger than the diameter of the fastener, to avoid the chance of overstressing the fastener in shear (whilst also allowing for some zinc build-up if one or both parts to be connected are hot-dip galvanised).

Most often, these holes are located next to each other, or are spaced apart next to a solid object.

Refer for example to the *top* image in *Figure 583* which is an extract from drawing EL0011055 ("Post Type Insulator on Mast"). In this case, a tight bolted connection can be made because the bolt compresses solid objects together, i.e. steel bracket (lower end) against flange of a steel UC structure, against steel backing plate (upper end). Reasonably high bolt torques can be set.

However, in some situations, such as that shown in the *bottom* image of *Figure 583* (with the same mast now rotated 90°), the bolts clamp against an open space. In this case, the strength of the structure (the UC Mast) has to resist the bolt tensions to give a reasonable amount of plate grip onto the structure. If too much bolt tension is applied, then the attachment bracket and/or backing plate may tend to bow (and possibly the flanges of the mast too), which is not a desirable outcome.

So, this latter situation needs a bit more care when fastening the bolts. Ideally, bolt torque settings (with tolerances) should be specified, and a torque wrench used to set that tension.

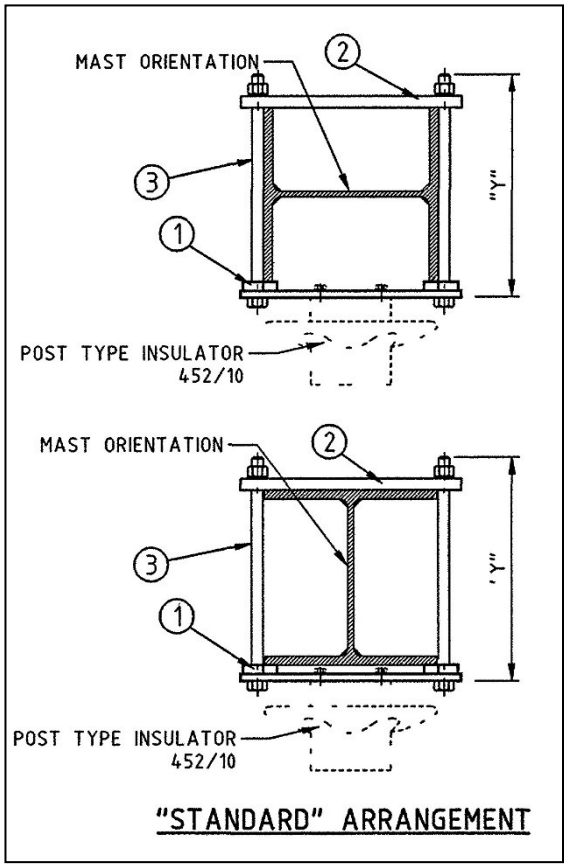


Figure 583 - Bracket connection using backing plates

Unfortunately, the majority of situations of backing plates on UC masts are this latter case, e.g. the various standard cantilevers installed on a 250 UC mast.

CLEAT CONNECTION

A "cleat" connection relies on a bolt & nut fastener applying pressure to the cleat body, which in turn clamps onto another member further out at a convenient location.

A common application is the connection of an OHW bracket to the flange of a steel section, as depicted in *Figure 584*, which is also extracted from drawing EL0011055 ("Post Type Insulator on Mast").

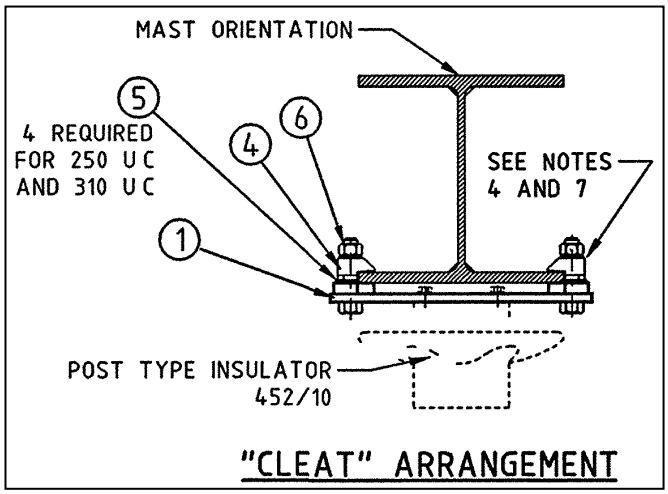


Figure 584 - Cleated fitting using "Lindapters"

The advantage of this approach is that it requires a hole only in one of the two components being connected (and of course a hole in the cleat itself) – there's no need for a hole in the part it's connecting to (the flange in this example).

This usually means the cleat can be positioned where it needs to go along the member being connected – offering continual adjustment. In the view of *Figure 584* this means the bracket can move along the U.C. flange either up (out of the page) or down (into the page).

It also means that a similar cleated arrangement could be installed on the unused opposite flange, and this is particularly helpful in back-to-back cantilever situations on a common mast or drop vertical located in between tracks.

The key to the success of cleat fittings lies in the *tail* (or *heel*) of the cleat closely matching the thickness of the part being connected to. Sometimes this means adding a washer to help build up the heel distance to suit, e.g. almost the thickness of the flange in the above drawing.

The result should be that the cleat applies a relatively uniform force to the part being connected (i.e. the clamping pressure is spread over an area and not located at one point).

There happens to be a large range of cleats used in the OHW system. The following lists a few of the more common types and applications. See *Figure 586*.

- "Railway cleats" – Fitting series 151 to 159, etc. This style of cleat has been around since the early days of electrification. See left image in *Figure 586*.
  This cleat is simply a bent piece of 10mm or 12mm thick steel plate (of differing dimensions) with a hole in it, and galvanised. The rather huge range of cleat fittings results from the need to connect OHW brackets to the variety of thicknesses of steel members on bridges and other structures where OHW is attached. (The variations in steel members thickness is part of the problem.) See *Figure 473* further back for an example of how they can be used under a bridge. Lindapters (see below) seem to offer a superior solution these days.
- "Lindapters" – these are commercial cast cleats that can be used in a multitude of situations. See Item 4 in *Figure 584* and centre image in *Figure 586*.
  This fitting offers a very neat and flexible cleating solution, with teeth at one end to help lock onto the connecting steelwork.
  There are 2 types:
  Type "A" has a recess to take the hex head of a bolt or nut, which then captures it and prevents it from turning.
  Theoretically, this eliminates the need for a second spanner when tightening the assembly.
  Type "B" has a flat surface, so 2 spanners are needed to tighten it.
  Type B is preferred because the bolt can only go one way in Type A, and this has caused electrical clearance problems in the past (the end of the thread came too close to the pull-off post type insulator).
  Their "clipped washer" (CW) is an accessory that helps build up the thickness of the tail of the Lindapter, to better match the thickness of the steel member being connected to.
  It seems the most popular Lindapter for OHW is the "B20L" (*Figure 585*) which is Type B, designed for M20 bolt, and with a 'L'ong tail ('S'hort & 'M'edium tails are also available), and they sometimes need clipped washers (CW). They are used for 20mm bolted connections to a mast, drop vertical, portal leg or portal bridge.

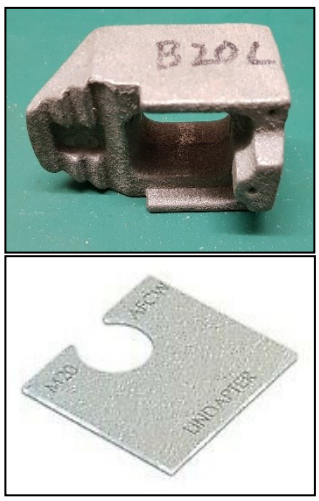


Figure 585 - Type "B20L" Lindapter & Clipped Washer

  One of their features seems to be that, if they become loose (for whatever reason), they can rotate slightly and, in doing so, jam against the flange of the structure, thus preventing any further movement. Refer to *Section 5.2.7*, *Example 2* for an example of how this can be a problem for some staff who are unaware of this characteristic.
- "Cable cleats" – Fittings 330/18 & 330/32 are designed for holding single and twin 95mm² bonding cables (respectively) to a structure. See right image in *Figure 586*.
  Fitting 330/33 is for connecting single 120mm² bonding cable to a structure. (These cleats are normally spaced up to 1m apart along the length of the cable route.) The design of the cleat is such that the cable is firmly held against the structure as the fastener is tightened.

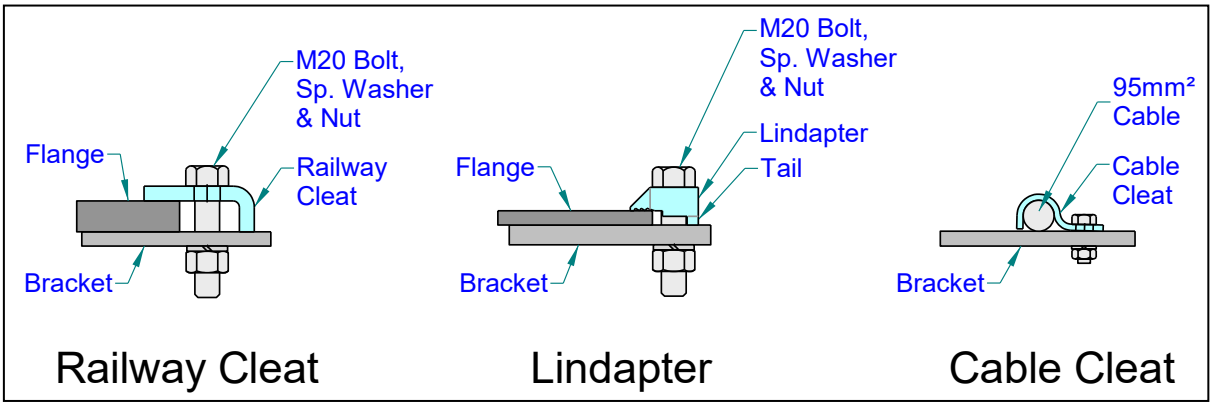


Figure 586 - Common types of Cleats for OHW

An example of some poorly installed "Railway" cleats is given in *Figure 587*. They're installed on a simple suspension bracket that's meant to be firmly held to the underside of the portal bridge, providing a catenary suspension point.

Here, these cleats aren't properly designed for the support bracket called up. The heel end does not fit onto the bracket. The left one is totally off the bracket, and is instead jammed in place, which is woefully inadequate. The right one is rotated so that the heel partly rests on the bracket. In either case, it wouldn't take much effort to cause one or both cleats to totally dislodge, and the OHW fall to track. Also, the bolts are meant to be vertical, but in both cases this is not so (the left one in particular is in serious trouble).

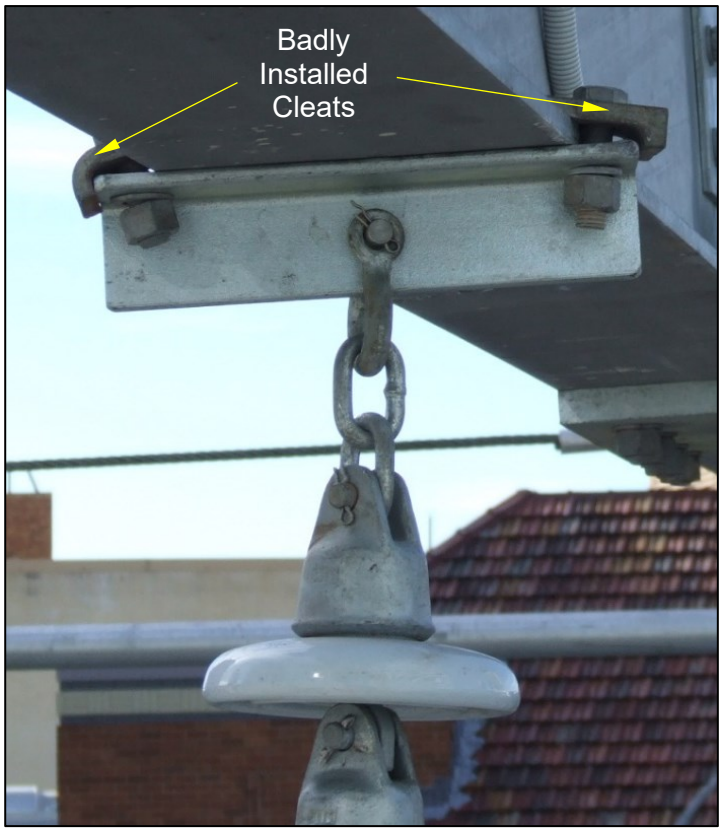


Figure 587 - Badly installed cleats

CLAMP CONNECTION

A multitude of clamps exist in the OHW system, and many are intended for clamping tightly onto a wire. This is done for the following reasons:

- To attach a piece of equipment to the wire. This is usually done in a way that does no harm the conductor (i.e. no sharp edges to cut into the wire's outer strands), so bellmouth (radius) edges are provided on the clamp. Examples:
  - Fitting 187 is a clamp that connects a catenary wire to a bridge L-iron arrangement or the like.
  - Fitting 61/2 is the standard contact swivel clamp, which connects the pull-off arm to the upper wedge-shaped grooves in the contact wire.

- To pass heavy dc current from one conductor to another. Various gunmetal U-bolt clamps are available to do this – most connect 2 conductors, but some allow connection of 3 conductors together (the so-called "triple clamp"). Examples:
  - Fitting 463/21 connects a 90mm² HDBC wire back onto itself when looping around another fitting.
  - Fitting 54/17 connects 270mm² to 90mm², and
  - Fitting 54/37 connects 270mm² to 165mm² to 90mm² wires (triple clamp).
- To connect one wire to another whilst offering a "soft" interface. Example:
  - Fitting 168/3 clamps onto a 270mm² catenary wire, and allows a 90mm² wire to lasso around this clamp (which itself is terminated with a 463/21 clip), for span connection to the catenary wire. This is a very common arrangement, offering lots of protection to the outer strands of the vital catenary wire.
    Note that a direct connection of these 2 wires together without such clamp would likely not last long before stranding of one or both wires takes place.

5.1.21 Adjustability

The provision of some form of adjustment is extremely advantageous to the OHW system, especially in regard to the support & registration arrangements. Of particular note is the need for the all-important position of ***contact wire relative to track***, both horizontally (***stagger***) and vertically (***height***), and some provision for adjustability can help achieve this, especially if the track becomes way out of its correct design position.

There are times during construction of the OHW, where things don't go quite right – something unforeseen is in the way, or a mast was stood in the wrong position, etc. Track possessions are a crucial time (meaning they're hard to come by, limited in duration and expensive because of the alternative transport arrangements needed). So, during the possessions any delays should be avoided, and if there's no provision for some OHW adjustment that's needed, then this can delay the project while an alternative solution is found. This is risky because the solution may not be as well thought through (may fail). So, it's in this situation where the desire for OHW equipment adjustability comes to the fore.

The various OHW cantilevers that support the OHW have a generous amount of adjustability built in to their design – so much so that they tend to resemble something made from a giant "Meccano" set.

Adjustability can take on 2 forms:

- "Discrete" adjustment (with telescoping tubes or side plates, employing holes for pin connections), and
- "Continuous" adjustment (with sliding parts and utilising bolts to clamp parts together at a particular position).

5.1.21.1 Discrete Adjustment

Generally speaking, Sydney's OHW system has tried to standardise on any discrete adjustability in increments of 50mm.

- Chain links are 50mm long,
- Various holes in parts of the *Mark-2 cantilevers* (for 16mm diameter stainless steel pin connections) are usually spaced 50mm apart. Likewise with *tunnel cantilevers*, etc.

The maximum error when dealing with 50mm spacing is ±25mm (any larger error would lead you to select the next hole, if one is available).

Some common sense decisions were made in the 1980s when the latest *Mark-2 cantilevers*

were developed, to try where possible, for "discrete" adjustments in preference to the "continuous" alternative. The argument then was that it's easier (and more reliable) to direct someone to install a pin in a particular hole in a fitting, than to measure along a certain distance and clamp a fitting. For example, instructing the installer to use "Hole 3" instead of telling them to measure 645mm along a length of steel, is likely to achieve greater success and probably a quicker outcome. And you can see at a glance later on if this was achieved.

The error in using the discrete "hole" method was deemed to be very small and thus acceptable in terms of overall tolerances. And the outcome would be more reliable than getting someone to read numbers on a ruler or tape measure.

It was also decided to use standard 16mm diameter stainless steel pins (with hump-back split pins at each end to trap the pin in the assembly – see below), wherever this was practical. The alternative method was to use nuts & bolts which required tightening, along with spring washers or other methods to prevent the nut coming loose. The 16mm pins are mostly in the 511/- series, with 511/32 being the most popular.

The main reason this was done was because a pin is much quicker to install and remove for adjustment, in situations where there is no need for clamping pressure (otherwise a threaded fastener is needed).

As a consequence, the Mark-2 cantilevers mostly have holes left, right and centre (so to speak). Chain links offer adjustment to the top of the cantilever frame (triangle support), and discrete holes provide adjustment in contact (and catenary) stagger, and in some cases their height too.

Of course, the constructors needed to know which direction the holes were numbered, and even to this end there is a logical and consistent method –
hole numbers increase laterally towards the track or downwards also towards the track.

The "CCalc" and "Mast" computer programs know the adjustability provisions of each support & registration standard arrangement, and they allocate the appropriate adjustment holes and dimensions for construction, to deliver the correct contact height and stagger (within tolerance).

HUMP-BACK SPLIT PINS

Stainless steel pins are used in all sorts of OHW equipment, and the ubiquitous 16mm SS pin normally traps the parts being connected by having "hump-back split pins" installed at each end. This is the most common pin to provide the discrete adjustment mentioned above. Refer to *Figure 588*.

The relative simplicity offered by the industry-standard hump-back split pins has led to them to being adopted as a means of capturing the ends of all sorts of stainless steel pins in Sydney's OHW system.

There are 2 standard stainless steel pin diameters:

- *16mm* (for medium loads, such as encountered in support & registration arrangements), and
- *19mm* (for larger loads, including anchoring conductor tensions).

Both these sizes can use the same size hump-back split pin – the *HP/A* pin, as defined in Australian Standard AS1154.2 and suitable for diameters 16mm to 20mm.

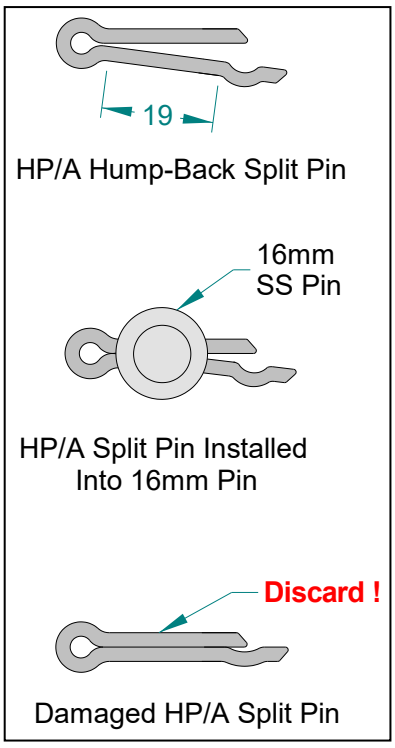


Figure 588 - Hump Back Split Pin

(Note that the larger *HP/B* size is used for larger pin sizes of 22mm to 24mm diameter, and so has no application here.)

The hump-back split pin is made from stainless steel wire of semi-circular cross-section and 3.6mm in effective diameter. It has 2 legs that are splayed out, and these legs want to spring back to this shape even after the legs are compressed together during installation.

The hump is sized to fit through a hole by compressing the 2 legs together. When the hump passes out the other side of the hole it's meant to spring back outwards as much as it can, leading to a firm hold in the pin hole. The hump, with outward pressure against the hole, prevents the split pin from passing back through the hole and dropping out.

The benefits of this pin in the OHW system are:

- They offer a simple, cheap and secure way of terminating one or both ends of a 16 or 19mm pin.
- They are made from spring stainless steel, so they will not corrode and should last the life of the associated equipment in the outside environment.
- They are an industry standard split pin (their shape is governed by an Australian Standard), so they should be readily available and of good quality.
- There's no need for any special tools to install them (although pliers may sometimes be needed for their removal).
- They are a reusable item (provided their shape hasn't been damaged – see below).

The main problem with hump-back split pin is that sometimes people wrongly grab the head of the split pin across the return diameter using pliers, in a way that permanently compresses the 2 legs together, thus losing its spring action. This can lead to the split pin readily falling out. These damaged split pins must be discarded in a way that *prevents their reuse*.

The other problem experienced over time is a manufacturing quality issue – sometimes the dimensions aren't to the Australian Standard, making the split pins difficult to install in the hole, or conversely, they can easily fall out or rattle in the hole.

When installed, the legs of these pins are meant to press against the hole in the main pin so that it doesn't rattle. In the OHW environment, anything that's loose and rattles can wear out over time, especially with the vibrations generated by the multitude of passing trains (with their several pantographs raised) every day.

Figure 589 is an example of a damaged hump-back split pin being installed (on a *Mk-2 Tunnel Cantilever*), and left without one of its legs – the one with the all-important hump! There's very little to keep this pin in place, especially with the head located at the bottom and ready to drop. Yet someone thought this was acceptable!

Figure 589 - Damaged Hump Back Split Pin missing a leg

5.1.21.2 Continuous Adjustment

There are times when measurements need to be made so that parts can be accurately clamped at the right location, and discrete adjustment cannot easily be provided. This is where continuous adjustment is appropriate.

For example, the placement of the 2 or 3 attachment brackets on a mast for various cantilevers. These brackets are located a certain distance up from a reference point (ideally a

survey nail installed lower down on the mast).

But even here it was decided to round the numbers to the nearest 10mm, because this makes it easier for field staff to interpret and get right. For example, it's easier to understand what 5.64m is than 6.543m (= 3mm error). The consequence of the resulting error in this approach (±5mm) is less than the general OHW tolerance of ±25mm, and is relatively insignificant in the scheme of things.

5.1.21.3 Alternative Use of Discrete Fittings

Instead of providing some adjustability mechanism between 2 fittings (as described in the above 2 subheadings), there are times when the adjustment is considered best met by installing *single fittings made in incremental lengths*.

For instance, various series of pull-off arms and contact knuckles come in discrete lengths, typically in 50mm increments and over some range of lengths.

A specific example is the current horizontally-pivoting twin-contact pull-off arms on the Mk-2 cantilevers:

> 955/21 (1,050mm long) to 955/36 (1,800mm), which are in sequential increments of 50mm throughout this length range (drawing EL0017022).

This allows selection of a specific length of pull-off arm to suit a situation where no other form of adjustment can be made, such as a pull-off arrangement on a drop vertical that's sandwiched tightly between 2 tracks, with just enough room for some compressed form of contact registration.

Over time there have been a number of attempts to provide some adjustability of knuckles – see *Figure 590*. This configuration is no longer deemed desirable or acceptable (for reasons, see below).

Figure 590 - Adjustable Knuckles (not desirable)

The same with "adjustable" pull-off arms, by bolting 2 overlapping steel flats together through appropriately spaced holes, and changing their overall length in the process. This approach is seen in *Figure 591*, which was proposed (but ***not accepted***) for a recent tunnel cantilever.

TO MINIMISE THE RISK

Because the immediate interaction between contact wire and pantograph is crucial to the reliability of train running, it deserves special treatment when it comes to the OHW fittings that are installed at or near this level. Vibration is often generated in this interaction, and so fittings need to be able to cope with this movement without falling apart or becoming loose over time.

So, the best approach for minimising problems, especially for main lines and other heavily trafficked and strategic areas of the network, seems to be to *keep things as simple as possible*. In which case, the extra cost of providing a greater number of discrete length fittings is deemed worth it, particularly considering how many decades typically this equipment is in place!

By using simple ***discrete length arms*** there's less chance of someone doing the wrong thing, and it not being picked up and corrected!

Such wrongs include:

installing fittings incorrectly, or not tightening the bolts sufficiently, or someone forgetting to install a vital spring washer, etc.

In the case of twin arms installed side-by-side, if the fastening nuts were installed between the arms (instead of on the remote side), this can cause an uplifted arm to snag on the nut of the adjacent arm and cause problems.

So, instead of the approach of *Figure 591*, discrete arms are used with the *Mk-3 Tunnel Cantilever* arrangement. This has incremental lengths of flat steel, each with a hole drilled in one end and a vertical tube welded at the other end, then galvanised – simple and effective. They are Fittings 964/1 to 964/9 (500mm to 900mm respectively, in 50mm increments, per drawing EL0357172) – *Figure 592*.

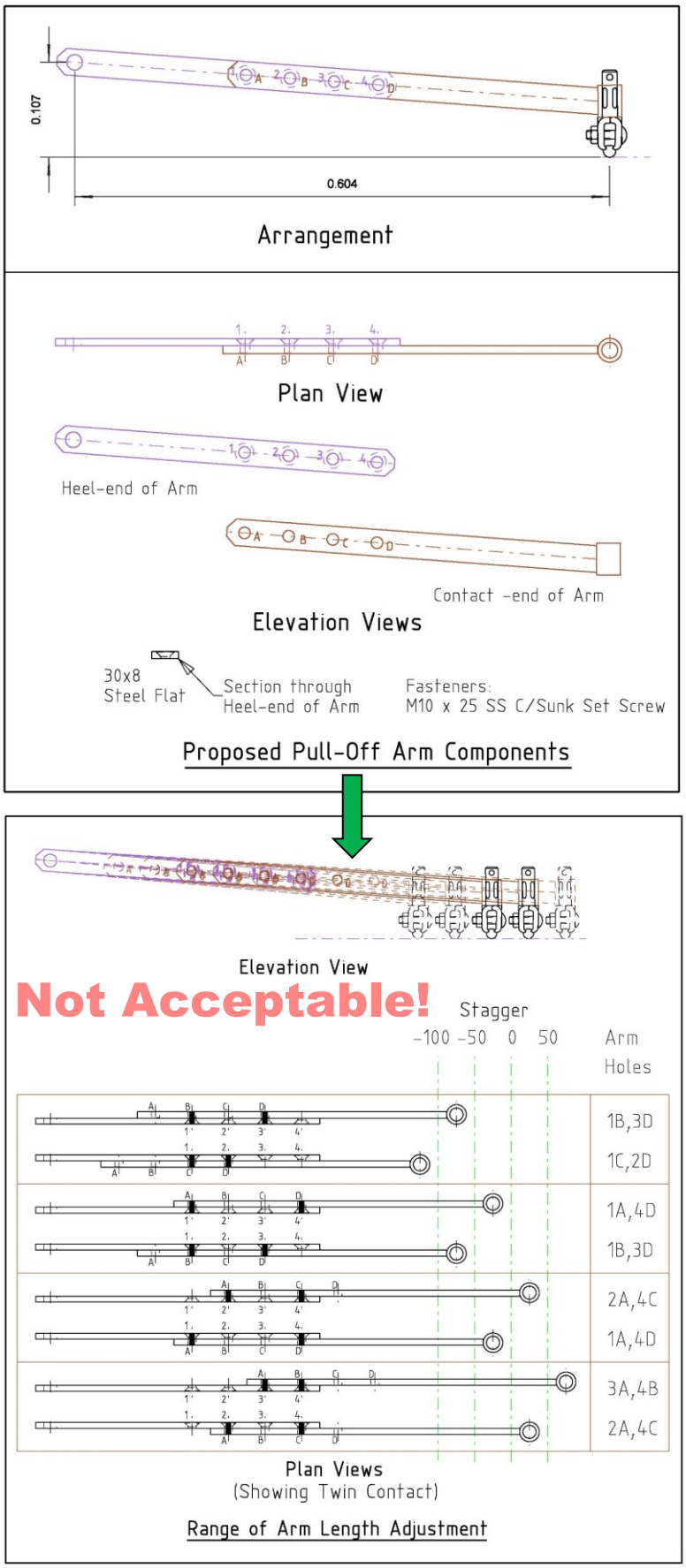


Figure 591 - Proposed Ajustable Arm (not accepted)

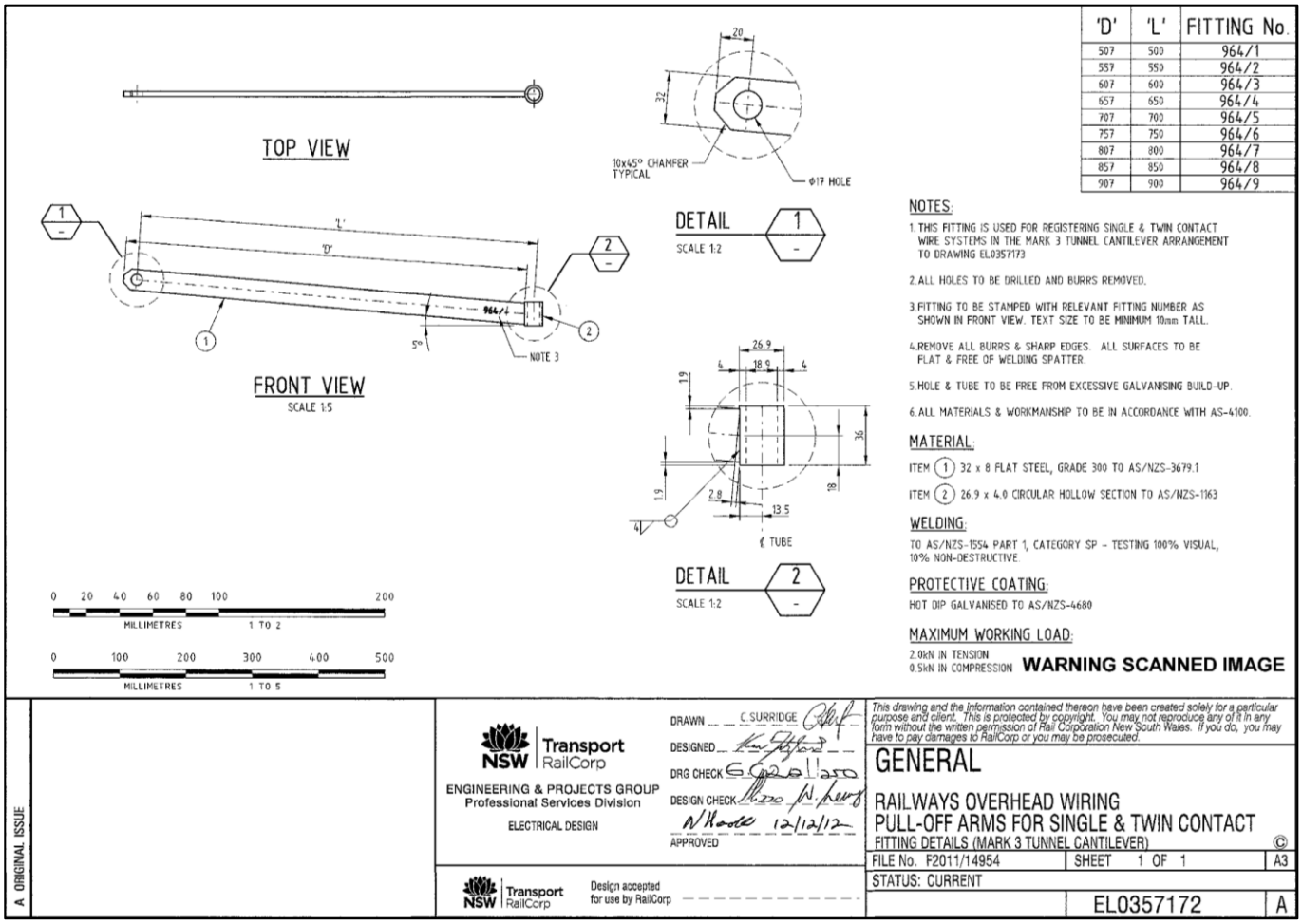

TOP VIEW
FRONT VIEW
SCALE 1:5
DETAIL 1
SCALE 1:2
DETAIL 2
SCALE 1:2
10x45° CHAMFER TYPICAL
Φ17 HOLE
NOTE 3
℄ TUBE
'D' 'L' FITTING No.
507 500 964/1
557 550 964/2
607 600 964/3
657 650 964/4
707 700 964/5
757 750 964/6
807 800 964/7
857 850 964/8
907 900 964/9
NOTES:
1. THIS FITTING IS USED FOR REGISTERING SINGLE & TWIN CONTACT WIRE SYSTEMS IN THE MARK 3 TUNNEL CANTILEVER ARRANGEMENT TO DRAWING EL0357173
2. ALL HOLES TO BE DRILLED AND BURRS REMOVED.
3. FITTING TO BE STAMPED WITH RELEVANT FITTING NUMBER AS SHOWN IN FRONT VIEW. TEXT SIZE TO BE MINIMUM 10mm TALL.
4. REMOVE ALL BURRS & SHARP EDGES. ALL SURFACES TO BE FLAT & FREE OF WELDING SPATTER.
5. HOLE & TUBE TO BE FREE FROM EXCESSIVE GALVANISING BUILD-UP.
6. ALL MATERIALS & WORKMANSHIP TO BE IN ACCORDANCE WITH AS-4100.
MATERIAL:
ITEM (1) 32 x 8 FLAT STEEL, GRADE 300 TO AS/NZS-3679.1
ITEM (2) 26.9 x 4.0 CIRCULAR HOLLOW SECTION TO AS/NZS-1163
WELDING:
TO AS/NZS-1554 PART 1, CATEGORY SP - TESTING 100% VISUAL, 10% NON-DESTRUCTIVE.
PROTECTIVE COATING:
HOT DIP GALVANISED TO AS/NZS-4680
MAXIMUM WORKING LOAD:
2.0kN IN TENSION
0.5kN IN COMPRESSION
WARNING SCANNED IMAGE
MILLIMETRES 1 TO 2
MILLIMETRES 1 TO 5
A ORIGINAL ISSUE
NSW Transport RailCorp
ENGINEERING & PROJECTS GROUP
Professional Services Division
ELECTRICAL DESIGN
DRAWN C.SURRIDGE
DESIGNED
DRG CHECK
DESIGN CHECK
APPROVED
12/12/12
Design accepted for use by RailCorp
This drawing and the information contained thereon have been created solely for a particular purpose and client. This is protected by copyright. You may not reproduce any of it in any form without the written permission of Rail Corporation New South Wales. If you do, you may have to pay damages to RailCorp or you may be prosecuted.
GENERAL
RAILWAYS OVERHEAD WIRING
PULL-OFF ARMS FOR SINGLE & TWIN CONTACT
FITTING DETAILS (MARK 3 TUNNEL CANTILEVER)
©
FILE No. F2011/14954
SHEET 1 OF 1
A3
STATUS: CURRENT
EL0357172
A

Figure 592 - Accepted Pull-Off Arms for the Mk-3 Tunnel Cantilever

A similar situation exists for simple steel contact knuckles. (Note however that the current insulated knuckle arrangement does provide adjustability, but this is a deliberately robust configuration to cope with the situation – refer to *Section 3.1.5.4*, *Cycloaliphatic Resin Insulated Knuckles*.)

5.1.22 Threads

5.1.22.1 Using Stainless Steel for Fasteners

There was some mention of SS fasteners back in *Section 5.1.16.5*, *Stainless Steel*.

The majority of stainless steel fasteners used for various front line conductor clamps and attachments are of the M10 and M12 size, e.g. U-bolts, contact swivel clamp, etc.

These fasteners are mostly at 1500V potential, and some of them fasten gunmetal clamps that connect conductors together, that then transfers significant current (from copper to copper or an alloy of it).

It seems a policy was made many decades ago to standardise on stainless steel for these crucial fasteners. The last thing you want is for corrosion of normal steel bolts, even thought they would have been galvanised. This can be particularly nasty where part or most of the bolt is hidden by the clamp being fastened. Obviously, this hidden failure mode can cause significant problems in terms of reliability, since although you could probably pick up the signs of rusting on the outside of the clamp, you cannot always readily tell the degree of corrosion inside until it eventually breaks.

As I understand it, the main problem with using stainless steel in this situation is that passing dc currents through types of stainless steel can eventually cause damage to the internal crystalline structure of the SS, making it become brittle over time. So various attempts were and are made to prevent dc current from flowing through the stainless steel fasteners, or at least significantly limit the amount. This has often been accomplished by installing a small amount of insulation (of some form or other) in the current path.

5.1.22.2 Stainless Steel Thread Pitch

In relation to the above section on stainless steel fasteners, the standard commercial thread pitch for an M10 is 1.5mm, and for an M12 is 1.75mm – these are ***Metric Coarse*** threads. (Pitch is the distance between consecutive thread peaks.)

However, many decades ago it was decided that there were some benefits to be gained by using the ***Metric Fine*** thread which, for both M10 and M12 threads, is 1.25mm pitch.

As far as I understand, there were 2 main advantages to adopting the fine pitch thread when used to make electrical connections that's called on to pass heavy current.

Probably the major benefit has to do with providing a convenient and reliable means of attaining a *high contact clamp pressure*. The finer the pitch, the greater the tension that is ultimately applied to the fastener for the same applied torque on the nut (provided you don't strip the thread). Even moderate tightening of the nuts can generate huge clamping forces.

Importantly, this higher clamp pressure in turn reduces the electrical resistance across the joint, which is particularly important when passing heavy current (thousands of amps) in a 1500V heavy current OHW system. (The higher the joint resistance, the greater the probability that the connection will heat up to higher temperatures and eventually cause some damage to this connection over the long term.)

Another possible benefit was that *it removed the need for employing spring washers* (which were sometimes forgotten when installing fasteners anyway). Probably the argument was that the finer pitch, delivering a greater bolt tension and clamping force, made it less likely that the nut could come loose over time, so there's no need for spring washers in that case (?).

While attempts were made to standardise these fine pitch sizes for certain applications, unfortunately sometimes the course pitch was also used. This typically happened when commercial items (which used the standard pitch) were introduced.

However, a big problem happens when the wrong pitch nut is inadvertently applied to a bolt, usually resulting in threads quickly binding or cross-threading. Stainless steel threads are notoriously unforgiving when it comes to tightening the wrong pitch nut on a bolt – "galling" (see below) tends to be initiated, often with bad consequences (e.g. fastener has to be sawn off).

A good example of the mixing of threads happens on the standard "cable-to-aerial termination arrangement". This can be seen back in *Figure 449* and a photo is shown in *Figure 593*.

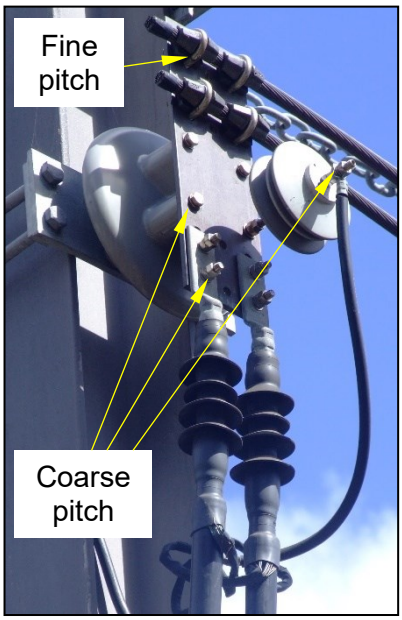


Figure 593 - Threads on Cable-to-Aerial Termination

This arrangement has a large, 10mm thick copper plate mounted on a post type insulator. At one end are the cable lugs connected to the plate using M12 *coarse pitch threads* (and using spring washers). At the other end of the plate are the various U-bolted aerial connections, which use M12 *fine pitch* threads (but no spring washers). You cannot afford to

make the mistake of mixing the nuts up when installing them here! The use, or not, of the spring washers is borne out in the standard arrangement drawing, per *Figure 449*.

Note that while most of the clamps need to pass heavy current, there are some that don't, but they still use the fine pitch thread.

A good example is the contact swivel clamp fitting (61/2) which uses 2 fine pitch cup head SS bolts. Even though ideally these clamps should pass no current, I think they have standardised the use of the fine pitch in this situation mainly to minimise the presence of the coarse pitch thread nuts, making it less likely that the wrong thread will be at hand. All good in theory.

Of course, the fine pitch still means that the clamping pressure of the swivel clamp onto the upper wedge shape of the contact wire is large, which is a benefit as this area is prone to much vibration and shaking around as numerous pantographs pass by each day.

Note that in the various feeding connections, the heavy current is intended to pass between copper lug and copper plate, with the several fasteners mainly there to apply the large connecting force that lowers the copper-to-copper resistance. But some minute amount of current will still flow through each fastener.

5.1.22.3 Galling

Stainless steel has many good properties for use as a metal in OHW construction.

However, it has one potentially nasty characteristic that is not widely known or understood – its tendency to damage threads by a process known as "galling".

Galling is the term used to describe the situation where a stainless steel threaded rod or bolt thread suddenly, and for no apparent reason, *deforms* as a stainless steel nut is rotated to tighten or loosen it. This means that the thread on the nut binds up until it effectively "welds" to the rod thread. The only way to remove the fastener then is to somehow saw the thread off.

This binding action doesn't always happen, but if it does, it can cause unexpected grief because it means the thread is often rendered useless, and an alternative approach may be needed in a hurry.

According to the *Stainless Steel Development Association*, galling "*is caused by cold welding of the high points of clean, oxide-free metal left when the oxide film is dislodged by surfaces rubbing against each other*". Of course, in our case the surfaces rubbing are the internal and external threads – nut and bolt. (Apparently aluminium and titanium also suffer from this unfortunate characteristic.)

Figure 594 shows a standard stainless steel mushroom-head, square-neck bolt with thread that's been damaged by galling. In this case the nut was able to be removed – only just. During the removal, the temperature of the nut rose dramatically as progressively more effort was applied to remove the nut.

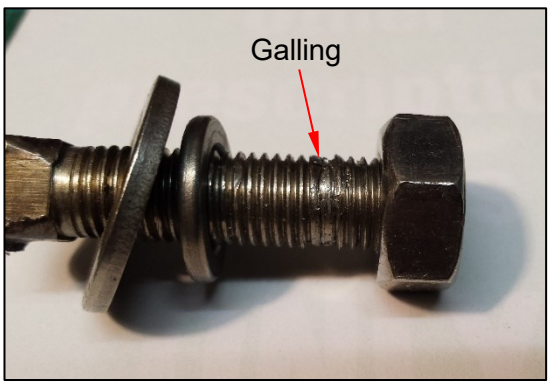


Figure 594 - Galling on SS thread

There are various anti-galling compounds available to help combat this problem. Products like *LOCTITE® 567™* can be used to help prevent the galling process initiating when screwing or unscrewing stainless steel threads.

The incidence of galling can be increased by using rolled thread with a rough surface, and also by having tight clearances between mating threads (nut & bolt).

In simple terms (and in my understanding), it seems that as soon as friction heats the nut, the expansion of the thread can begin to bind the thread interface in a compounding manner.

I think a way to help combat this is to use a nut and bolt with dissimilar hardness. That way, if any deformation starts to occur on the softer metal, it can be rethreaded by the harder metal in the process (i.e. one thread is forced to behave). This is good engineering practice anyway.

Examples:

This galling problem occurred a few times at North Sydney Station when rebuilding the OHW around 2013.

Figure 595 - SS nut ground off

Existing stainless steel catenary suspension anchor bolts (threaded rods), needed to be reused at several locations in the concrete roof of the station (they were under the air-space development). But in the process of installing new stainless steel nuts, 2 of the 4 of them ended up seized by this galling process (even though it was warned well before the closedown that this might happen and therefore to be extremely careful). By using an angle grinder, the Civil construction crew were able to grind away the bulk of the 2 nuts and remove them – see *Figure 595*. They then packed over the minor damage on the threaded rod with washers, and installed nuts on good thread (fortunately the exposed thread was long enough for this). However, this distraction wasted a few hours to correct the situation, on a weekend closedown where time is so precious.

Also at North Sydney, several new stainless steel threaded rods (24mm diameter from memory) were installed for a fixed mid-point arrangement for the new regulated OHW that was being built at the time. I think the rods were quite long at about 1 metre and embedded into the tunnel roof and underlying rock using epoxy chemical. They had installed a pair of SS nuts, locked against each other, to help apply tension to the rod to test the epoxy anchors. However, when they came to remove the 2 individual nuts, there were some instances where they seized due to galling. I was told that so much effort was applied to remove each nut that, instead, it caused the epoxied rod to unscrew from its set position!

5.1.23 Environmental Conditions

The OHW equipment has to operate under most adverse weather conditions, to ensure a reliable supply of electricity to the pantographs of each train. This means that the electricity needs to be available, and that the contact wire path remains suitable to interact with, and remain on, each of the train's several pantographs (4 on an 8-car consist).

5.1.23.1 Temperature

Generally, the OHW is designed for *ambient temperature extremes* from about -5°C to about 40°C. Solar radiation can further heat the conductors to higher temperatures.

The Blue Mountains area experiences the coldest conditions, so the Compound OHW system installed there has been designed for temperatures down to -8°C, although I'm sure colder temperatures happen from time to time.

In tunnels, the temperature extremes are much less severe, and depending on how far into the tunnel, the range could be reduced to between about 10°C and 30°C. The tunnel temperature can be influenced by the trains themselves through a "piston" effect, especially where the train is a tight fit in the single-track tunnel. Here, the volume of air ahead of the train tends to

be pushed ahead out of the tunnel while the air behind the train tends to drag the outside air inside. So, if it's extremely hot outside (40°C +), then this drawn-in air by successive trains, can cause the ambient temperature to be hotter, and thus the OHW will also get hotter. (The underground stations are likely to become quite hot also..) The heat pumped out from successive air-conditioned trains must also heat the tunnel environment to a degree (so to speak).

5.1.23.2 Wind

Generally, the wind speed used for the design of OHW is 130km/h. This value is used to ensure pantograph security, i.e. that the OHW contact wire always remains on the train's pantographs for reliable electricity supply.

The good thing about wind though, is its ability to help cool the OHW conductors, which can improve the current carrying capacity of the OHW system. The stronger the wind, the more cooling is achieved, and this is true even if the wind is fairly hot (but cooler than the wires).

I think a higher wind speed of 160km/h is still used to design and/or assess the strength of the OHW support structures so they don't collapse under these rather extreme winds.

Figure 596 shows the devastation to the OHW when large pine trees fell onto the OHW at Medlow Bath in the Blue Mountains, due to extremely strong winds in Winter, 2011. One of the train carriages was also severely crushed. (The row of tall, historic pines lining the rail corridor in this area were subsequently removed to prevent this recurring.)

Figure 596 - Damaged OHW Structures from fallen trees in high winds (July 2011, Medlow Bath)

5.1.23.3 Rain & Humidity

Rain and humidity generally affect the insulation level of the 1500V system from earth.

All 1500V insulators are designed with "sheds" and/or extended creepage paths that help prevent the pooling and continuous streaming of water, which could otherwise cause flashover and consequent tripping of the supply (affecting the reliability of trains).

Moisture on the surface of insulators can lead to an increase in dc leakage currents to earth and then to other nearby pipeline services, etc. This can lead to an increase in electrolysis corrosion problems if not properly handled. For further information, see *Section 2.9*.

Figure 597 - Heavy rain at Goulburn St to Central Viaduct

5.1.23.4 Lightning

Located mostly out in the open, the long lengths of OHW conductors and multitude of support structures are mostly exposed to the elements. They are therefore vulnerable to lightning strikes, unless some form of shielding is made available.

In terms of the effect on OHW equipment, lightning generally takes on 2 forms: "direct lightning strikes" and "indirect lightning strikes".

Direct Lightning Strikes – this is where the lightning bolt strikes directly onto the OHW asset. Depending on the amount of charge (energy) in the lightning bolt, this can have the capacity to do a great deal of damage, and can readily cause the OHW to fail, by conductor breakage (which admittedly is rare), insulator flashover, etc. If it strikes an OHW conductor, it can cause a travelling surge current wave. This wave travels in both directions on the OHW conductors, with half the surge current in each direction. It travels along the line until it flashes over to earth at some vulnerable point (or points) along the way.

Indirect Lightning Strikes – if lightning strikes near OHW conductors, this can induce a surge voltage into the line and cause a travelling current wave as described above, although generally of a lesser magnitude.

Figure 598 shows the damage caused by a lightning strike onto an OHW mast structure installed beside a cutting wall. The lightning struck the top of mast, and the surge current transferred to the steel reinforcing in the base, then flashed over diagonally down to an adjacent track located below. The close-up view shows the now-exposed steel reinforcing in the retaining wall where the lightning current exited the mast base / wall. Quite a bit of damage resulted. Importantly, it also demonstrates that lightning can do unpredictable things.

"Shielding" is one approach that could be used to combat lightning, by providing an alternative and more desirable target to the OHW. It can help to protect the OHW from direct lightning strikes, although nothing is guaranteed when lightning is involved. OHW and their support structures, located below ground level, can be afforded some level of protection. Also, tall buildings located next to the rail corridor can act as preferential targets.

Figure 598 - Lightning damage to Mast foundation

Note that transmission lines can have an *overhead earth wire* supported above the top of each supporting pole, and this wire acts as a shield throughout the bays to protect the multitude of conductors directly below – refer to right-hand side of *Figure 227* for instance. However, there are no such overhead earth wire schemes to protect the OHW from lightning, because this would likely be impractical (the wires would need to provide wide coverage to the various OHW runs in parallel across the track corridor, and for long track distances). And such a scheme would be very expensive.

1500V cables are the most vulnerable OHW equipment that are particularly susceptible to being damaged by lightning, and which can severely disrupt train operations. These cables need to be protected by surge arresters, which "clamp" (limit) the voltage spike across the vital XLPE cable insulation, and direct the surge to ground to minimise the chance of damaging other equipment.

For more information refer to *Section 3.9*.

5.1.23.5 Ice

Ice build-up on the OHW conductors can cause them to sag more under the additional weight of ice. They can also be under greater influence of prevailing winds, with the larger diameter of ice on the wire causing more blowout. (This is probably a far bigger problem with HV aerial lines where ice build-up on their much longer spans can have a far greater impact.)

Refer to *Figure 599* which shows how much snow and ice can quickly build up on OHW equipment – cantilevers and wires. (Although I well remember this event, unfortunately I don't know who it was from the District that sent this amazing picture into the Design Office / Standards at the time.)

Figure 599 - OHW Cantilevers & Conductors covered in snow (Blue Mountains, 14 Oct 2014)

In regard to the contact wire, I understand that any ice build-up can be knocked off by passing pantographs. The first train of the day would probably have the biggest amount of ice to contend with.

Arcing from pantograph to contact wire (separated by a thin layer of ice) may be an issue though. Any such arcing has the potential to damage both sets of equipment.

In regard to conductors generally, as trains draw heavy current, this heats up the conductors which can help melt and shed any ice build-up.

5.1.23.6 Pollution

The main OHW components affected by pollution are the various 1500V insulators, and this can directly affect reliability. Corrosion of steel parts is another problem with some types of pollution.

A large amount of pollution build-up on the surface of insulators can lead to increased dc currents leaking to earth (with possible electrolysis issues), and it can be so great as to cause the insulators to eventually flash over. Under certain circumstances this can trip supply, affecting train running. Sometimes this can be a difficult type of fault to locate, due to the many kilometres of OHW being regularly supported by the insulators – where to look?

Pollution can take the form of salt spray when located near the ocean, industrial chemical pollution when in the vicinity of heavy industrial works, or (more immediately) the exhaust from steam trains and diesel trains – see *Figure 600* for instance. (I think these magnificent photos were taken by someone from the Electrical Standards group during a site audit.)

Figure 600 - A steam train billowing smoke onto OHW Insulators

Insulators located out in the open air are normally subjected to rainfall. The positive aspect of regular rainfall is that it can wash away some or most of the surface pollution before it gets a chance to really cake onto the surface. Suspension insulators have skirts on their underside that are designed to increase arc tracking distance, but unfortunately this area is likely to be sheltered from rainfall and so pollution may build up here. Manually cleaning the insulators may be necessary from time to time to reinstate the condition of the insulators.

Pollution build-up is worst where there is no rainfall to help wash it away. This is especially true under overline bridges and inside tunnels, although sometimes the train-generated wind may help blow away some of the pollution.

OHW located near the ocean, in particular, has to deal with the corrosive properties of salt spray, especially on the galvanised coating of various steel parts. There have been instances where the galvanising has not lasted more than 5 years (normal life is expected to be 30 years +). Locations along the Illawarra line approaching Wollongong and Kiama are particular nasty spots for this type of pollution. Thicker galvanising coatings, or applying epoxy paint over the galvanising, have been ways of combating this problem, but eventually the pollution wins (with the aid of time and the elements).

Figure 601 - Stalactite from Over-Line Bridge (Waverton)

Pollution problems can also come in the form of gradual chemical build-up under an overline bridge, such as that shown in *Figure 601*. A stalactite can form, that slowly reduces the required electrical clearance to the catenary wire or other live equipment. This issue is discussed further in *Section 6.4.1*, *Overline Bridges*.

5.1.23.7 Wildlife

Being mostly exposed to the elements, OHW is susceptible to the effects of wildlife activity.

The most common problem is the establishment of bird's nests amongst the OHW equipment. Refer to *Figure 602* and to *Figure 603*. You have to feel sorry for the birds though, with the numerous passing pantographs disturbing their social life (not to mention sleep)!

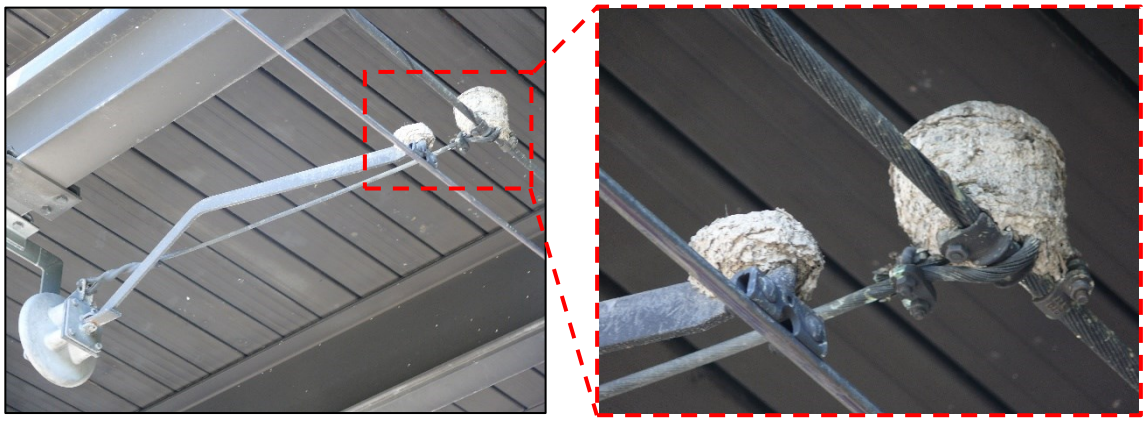


Figure 602 - Bird's nest on Cantenary & Contact fittings under bridge

Figure 603 - Bird's nest in Feeder Jumper

5.1.23.8 Adverse Condition

At a support & registration location where the pull-off arm is held by a *span wire*, the "adverse condition" is a check that there is sufficient radial load on the contact wire for it to hold the weight of the pull-off arm in place, as wind blows against and counteracts the radial load (the *reverse wind load*). The condition is:

Adverse Load = (Contact Radial Load - Contact Wind Load) > 250N.

In other words, even with strong wind blowing against the radial load, there needs to be at least 250N of force keeping the arm in tension.

The risk under conditions of strong wind, is that the heel end of a pull-off arm may not be sufficiently held up, and instead may droop down into the path of a train pantograph and subsequently damage both the OHW and train.

This condition is only necessary for pull-off arms held by span wires. If the arm is supported by a rigid horizontal post arrangement, there's no need to check this.

Refer to *Figure 604*.

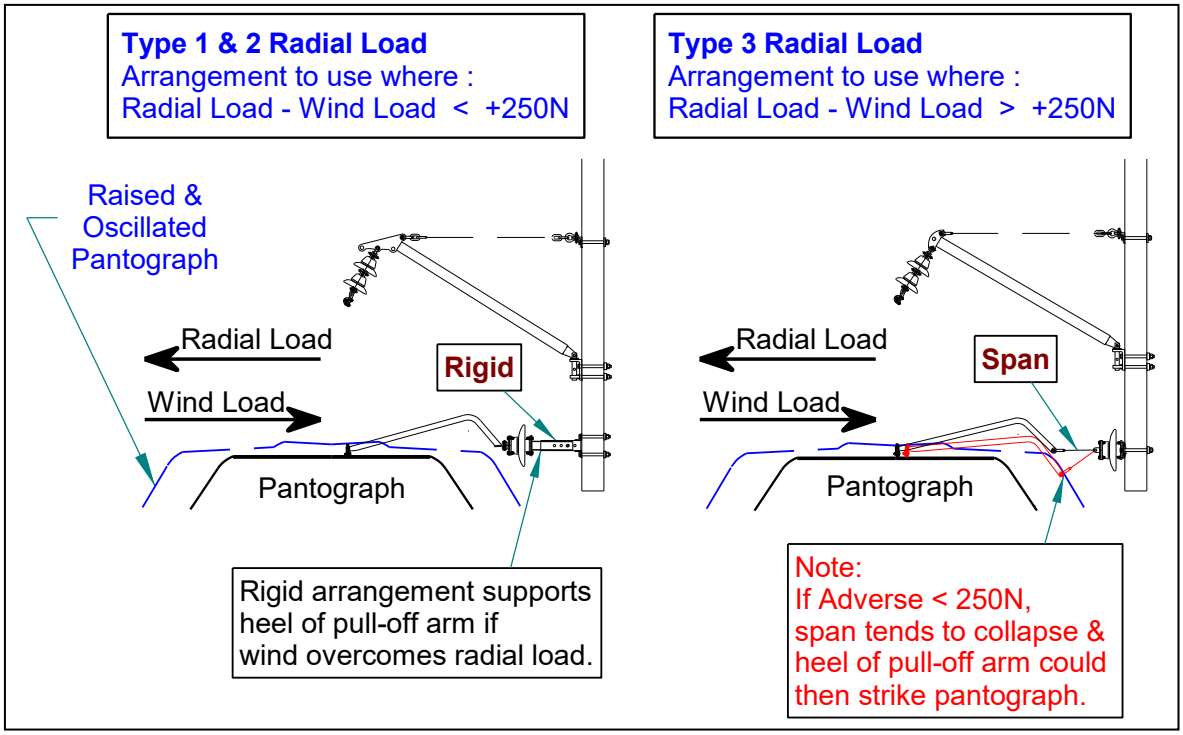


Figure 604 - Adverse Condition

The adverse condition separates the cantilever types, as follows:

- ***Types 1 & 2*** cantilevers and pull-off arrangements. These relatively low to medium radial load situations mean that, in many cases, the adverse condition cannot be met, so they normally require a *solid pull-off arrangement* to hold the heel of the arm in place. (It then means that you don't need to check this condition as it becomes irrelevant since a solid pull-off support is employed as standard.)
- ***Type 3*** cantilevers and pull-off arrangements. These have high radial loads, therefore the adverse condition is met. In this case they can use a lighter and cheaper *span arrangement* without risking pantograph damage.

The calculation for ***adverse condition*** differs for regulated and fixed-anchored OHW.

For ***Regulated*** OHW:

Adverse Load = Contact Radial Load - Wind Load (@130km/h)

For ***Fixed-Anchored*** OHW:

Adverse Load = the lesser of …

a) **Contact Radial Load (@ 40°C) - Wind Load (@80km/h)**,
[⇨ Low conductor tension with Medium wind speed], and

b) Contact Radial Load (@ 0°C) - Wind Load (@130km/h)
[⇨ High conductor tension with High wind speed].

In any OHW project, calculating adverse conditions for fixed-anchored OHW is much more involved than for regulated OHW.

Note: usually condition (a) above prevails in fixed-anchored OHW – that's why it's in **bold** type.

5.1.24 Clearances

For the most part, OHW conductors are exposed to the outside surroundings, and so the safe and reliable operation of the energized OHW relies heavily on maintaining certain minimum clearances to any nearby objects.

Generally, a ***150mm minimum electrical clearance*** is applied to the insulation of the various types of live equipment. For example, the standard post type insulator 452/10 (resin) is 156mm long from end to end, so steel plates bolted to the insulator ends will be spaced just over 150mm apart. The string line (shortest) distance from metal to metal passing over the edge of the resin insulation will give a far greater distance than this – more like 230mm as shown in *Figure 605*, and this helps deal with lightning surges (to a degree).

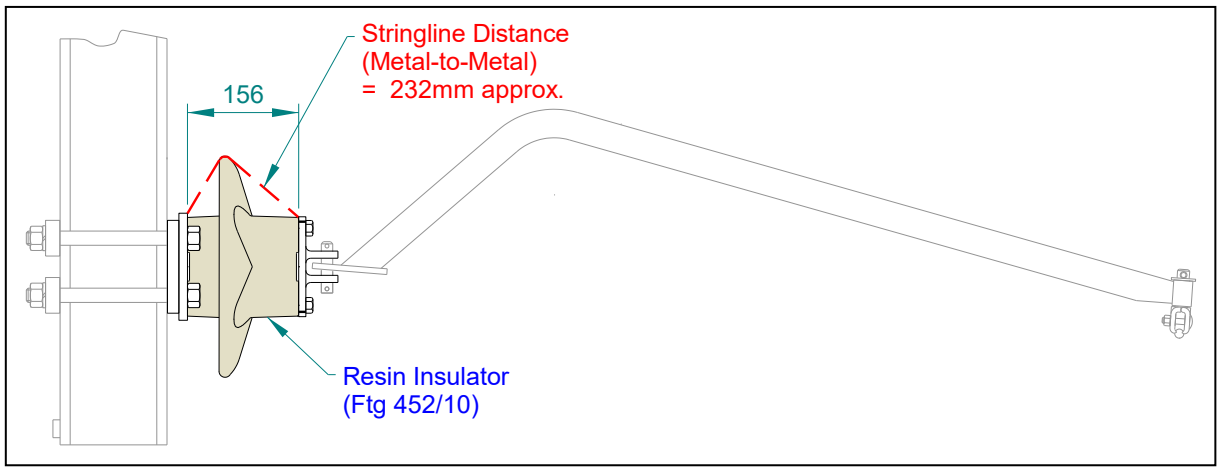


Figure 605 - Stringline distance across Post Type Insulator

As described near the start of this document in *Section 2.5*, the 150mm electrical clearance ensures that, if an arc were to be somehow established, it is likely to be rapidly extinguished (it is not self-sustaining). An extremely brief arc time minimises the amount of energy in the arc, and thus the level of damage caused by the arc is smaller than it could otherwise have been. Any extra distance helps to clear a lightning-induced flashover even more rapidly.

However, there are other clearances to be imposed in the design for the operation of the OHW, to minimise any problems. These clearances include (but may not be limited to):

- *Vertical clearance between the top of a train and the contact wire above*. A minimum contact height of 4.57m is required (under the worst/lowest conditions). This leaves 150mm to the top of a train (at 4.42m). See *Section 2.7 (a)* for more details.
- *Pantograph clearance to adjacent objects*, including station awnings, tunnel linings, etc. The "standard" static pantograph shape is appropriately "raised & oscillated" to include tolerances and dynamics during train running, then a 150mm "electrical clearance" envelope is added to ensure a safe distance is kept away from all sorts of other nearby objects. This can be somewhat deceptive, since a situation that has plenty of clearance to the contact wire (a station awning for instance), can have a vastly reduced clearance when a pantograph comes along – suddenly the lateral clearance can been reduced by more than 1 metre! (Refer to *Figure 660* further on.) So, because the train's pantographs are mobile things, a *Pantograph Gauge* is often employed to help determine or confirm suitable clearances to nearby objects. See *Section 6.3.2.3* for more details.
- *Vertical clearance from catenary wire to an overline bridge located above*. A minimum of 150mm is required under the worst case. However, the standards require even more clearance, depending on how far the closest OHW support point is from the clearance position. (The further away this support is, the greater the added clearance needed due to reduced control over the movement of the wire.) This depends on whether it's regulated

or its fixed-anchored OHW, and whether it's earthed metalwork or it's non-conductive earth, etc. For example, if the support is between 5 to 15m of the clearance point, then the vertical clearance needs to be increased to 200mm minimum, etc. Refer to the "Electrification Standard" EP-08000001-SP for the table of clearance values and situations.

- *Services erected above the OHW* – refer to EP-08000014-SP. This requires not just the minimum clearances, but also the method of attachment of the service so that it can be guaranteed *not to fall onto* the live OHW, e.g. double the number of fasteners holding the service in place, or halving their normal spacing. See *Figure 606* for example.

Figure 606 - Services erected above OHW (Epping to Chatswood Tunnel)

- *Level crossing clearances* – refer to EP-08000012-SP. This requires the contact height to be made higher to cater for tall vehicles crossing under the OHW, to maintain 1,000mm minimum electrical clearance to the vehicle under the worst case situation. Refer to *Section 6.4.5* for more details.
- *Solid safety barriers* are required in situations where people could otherwise approach too close to any live equipment. Refer to the standards for the current approach and relevant distances here. E.g. Standard EP-08000007-SP, "Safety Screens for Bridges Over 1500V Equipment".

5.1.25 Standardization & Spares

The standardisation of various OHW parts brings about many benefits – during the design of new or altered OHW, during installation, and with its maintenance into the future. Benefits include:

- Greater familiarity with the parts and how they behave, when designing, installing and maintaining (leading to less need for training),
- The range of spares is reduced,
- Subsequent big cost savings (economies of scale, minimised storage allocation),
- New equipment now requires a formal documented "failure modes" analysis (FMECA),
- Etc.

As a result of the above benefits, during the design phase it is somewhat desirable to keep to the common equipment wherever this is practical.

However, there may come a time when nothing suits, and a new type of part or equipment is required. Also, there's the challenge to know when new technology needs to be embraced. For instance, there are so many new materials on offer these days, particularly with plastics. And there should be an eagerness for change in this regard, where the outcome can offer an improvement in some way.

However, any new equipment requires a "Failure Modes, Effect & Criticality Analysis" (FMECA) to be conducted. This is required so as to determine the likely ways the new equipment can fail, the criticality of that failure to the OHW system, how to prevent such failure (preventative actions), and how to fix a failure if and when it happens. It also includes listing any spares and consumables required for undertaking these tasks, appropriate training, documentation, special tools required in performing the task, etc.

So, the FMECA process is obviously quite involved, but it should result in much better control over the introduction of new equipment to the OHW system, in so many ways. As such, it should be seen as an essential activity. But the information it provides also needs to be maintained into the future as things evolve.

5.1.26 Some Risks of Live OHW

A traction substation or sectioning hut has its various electrical equipment located within the confines of its building or fenced-off outside yard area. So, the operation of this equipment can be well controlled in this somewhat isolated environment.

However, the 1500V OHW system that it attaches to, has a huge exposure to the outside world, as the various wire runs generally follow the associated train track/s which radiate away from substations for many kilometres.

The fact that the OHW conductors are located above the track, which itself runs through a "rail corridor", is fortunate as it gives the OHW some limited degree of controlled isolation and protection against the outside world. (This at least is a better situation than that of the HV aerial lines which traverse all sorts of environments, including streets, to interconnect the substations.)

However, the increased risks (and associated consequences) of the *exposed* 1500V OHW are many and varied. They include:

- OHW 1500V *primary insulation failure*, which can liven up the attached steel structure (mast, anchor, overline bridge, etc).
- *Damaged train pantograph*, which can bridge between live OHW conductors and steelwork (including masts, overline bridges, etc).
- *Conductive objects* dropped onto or blown into the OHW, e.g. loose metal roofing materials.
- *Lightning strike*, which can cause failure of primary insulation, but the lightning impulse can travel further on the OHW and lead to problems elsewhere. (This risk is far greater for OHW than for substations, due to the sheer extend of exposure – many tens or hundreds of kilometres of wire compared to the land area of a large house for instance.)

Refer to Standard EP-12200001-SP, "Bonding of Overhead Wiring Structures to Rail" for prescribed locations that require bonding.

Refer to Standard EP-08160002-SP, "Safety Barriers for OHW Structures".

Section 3.12, (Bonding) also has more information on this topic.

5.1.27 Copper Theft

This aspect was mentioned briefly in *Section 3.12.0.5, Removal of Bonding*, but it bears to be expanded further because *copper theft* can be a significant ongoing issue these days.

The railways are not alone here – it affects other electricity distributors as well, although aluminium wire (which is much less valuable) can be, and is, an alternative to copper for high voltage *ac* circuits.

So why do thieves steal copper? Copper commands only about $7/kg (in 2020) which doesn't seem much, making one wonder why thieves would bother risking their lives (as well as the lives of others) by removing it from an electrical system.

However, if you look at a 270mm² catenary wire for instance, at a weight of about 2.4kg/m this represents about $17 per metre, and it soon adds up when many hundreds of metres are involved – 100 metres rolled up or cut into short lengths for easy transport could nett $1,700 !

It may also be the thrill of doing something illegal, or to cause disruption to train services, or as retribution for a late running train service – who really knows? Of course, the theft usually happens at night when the thieves are less likely to be caught.

The fact that the OHW is normally energized at 1500V usually deters thieves from stealing the catenary and contact wires and associated copper hardware in the air. However, during construction the theft of copper can be an ongoing issue. In recent years, some brazen thieves had even entered a secure compound during the day posing as if they were on a job, and then stole drums of copper (as well as other valuable items) – fortunately they were caught.

The thinner copper bonding wire is particularly vulnerable to being taken, as thieves probably think it is at earth potential (wrong!) and therefore safe to steal, which is of course extremely risky. And it's usually located closer to ground, making it less of a challenge to remove.

Steel wire has been used as a substitute for copper with some initial success, but it's much reduced electrical conductivity, and its propensity to rust in time, make it a far less desirable proposition.

Hiding the runs of copper (bonding wire) may seem a good thing to do in this case, however it can make the requirement to routinely check for visual continuity quite difficult.

The way that the thieves seem to know the specific risks involved, and what to do to avoid being electrocuted, does suggest that they had some training in the electricity industry.

Various schemes have been adopted, both here and overseas, to combat this ongoing problem. One of the simplest approaches is to get the scrap metal merchants to help out (if they're willing), noting that it's a criminal offence to deal in the stolen goods.

Refer to *Section 5.7.2.2*, *Example: Como, 1990* for an example of one of the serious consequences of copper theft.

5.1.28 OHW Design Process

Before any OHW can be built, or even modified in the field, all details of the *new arrangements* or proposed *changes to existing arrangements*, must be designed and signed off by people with appropriate Engineering Authority.

The design process takes the required outcomes of the project brief and combines this with the relevant standards and statutory requirements, to produce an OHW design that (ideally) is fit for purpose, requires minimal maintenance and should last many decades without problems.

Refer to *Figure 607*, which shows an older flow chart of the OHW design process that was used in Sydney's railways in the late 1990s. Although somewhat outdated now, it gives an idea of the general flow of things, and identifies some of the important interfaces with other groups (including signals and track).

OHW design essentially involves the *electrical / mechanical design* component which is the bulk of the effort in the flowchart, and a *civil design* component that's responsible for the construction of the various OHW support structures and anchors. Feedback between these 2 disciplines is vital at various stages during the design (including the final sizing of OHW structures, e.g. if a particular location needs a 250UC or 310UC mast).

There are several items missing from the chart that are required these days, including the need for an early assessment of the *risks and hazards* with that area and with the proposed changes to the infrastructure.

The designer is also responsible for issuing a set of *WeightSet* sheets for each *weight tension regulator* at all such locations – this helps to properly set them up to ensure they can travel up and down unimpeded throughout the extremes of temperature, and the resulting information is handed on for subsequent maintenance activities over time.

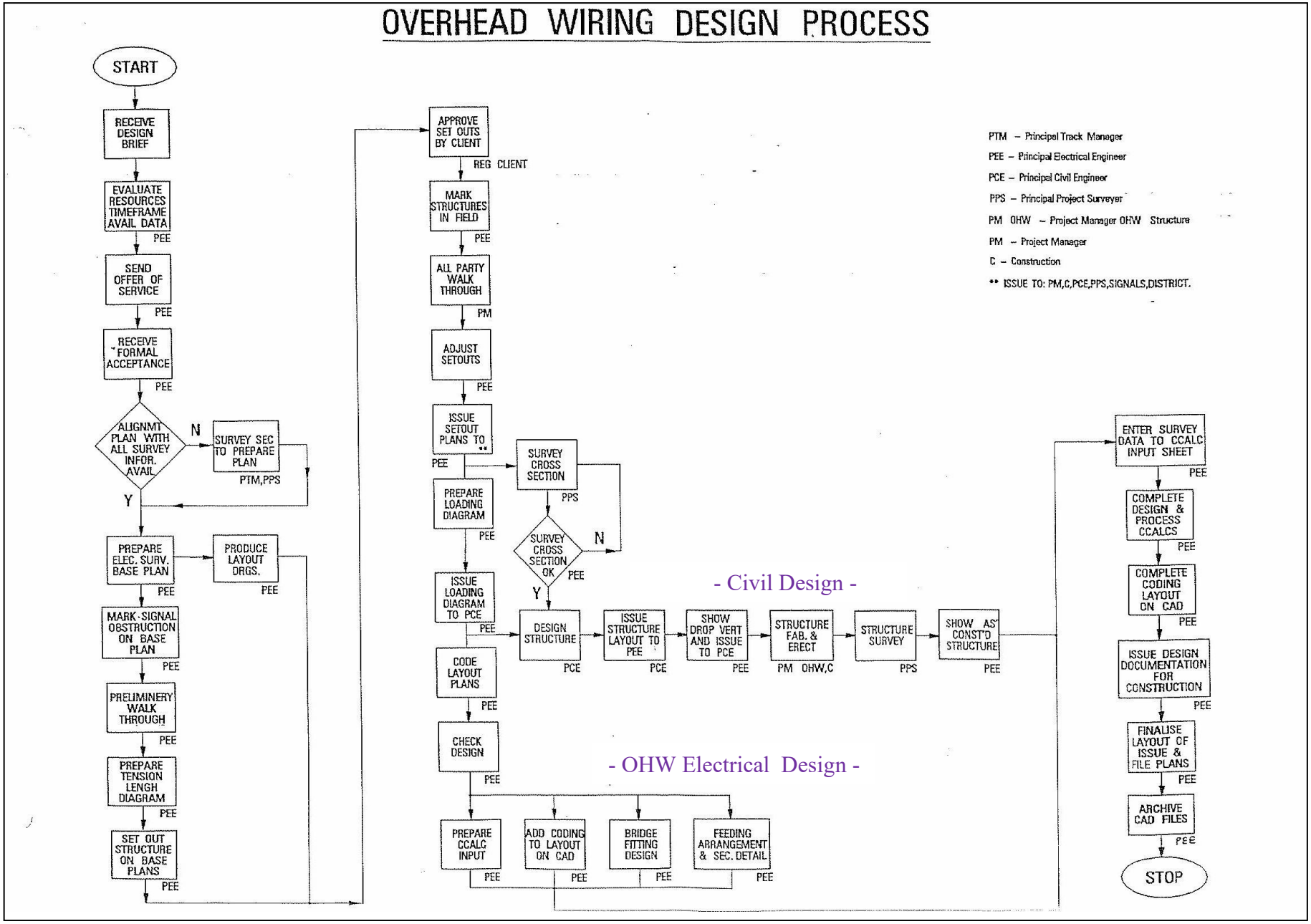


Figure 607 - Old flowchart of typical OHW Design Process

In some cases, there may be *heritage* aspects that need to be addressed in the design, such as having the OHW structures in a certain style and/or colour. For example, on the Sydney Harbour Bridge all new structures had to be of similar style to the existing ones, and painted "Sydney Harbour Bridge Grey".

There are usually interfaces with other systems that need to be addressed throughout the design. A good example is the *signalling* system (e.g. any signal sighting issues, location of OHW overlaps relative to stop signals, etc.).

As part of the design process for any project, there are one or more "All Parties Walkthroughs" carried out with various stakeholders, to enable feedback and help ensure there are no surprises at the end when the OHW is built and operated.

DESIGN CHECKS

One extremely important aspect of the design process is that there need to be *independent checks* performed during the design work. This is because the designer cannot always get everything absolutely correct – be they conceptual, in calculations, or in some other regard.

Having an independent design check performed is mandatory (and has been for a long time). It's meant to flush out all issues and calculation errors before construction begins, as that's when the big money is spent. Design is typically only about 5% to 10% of the total cost of a construction project, so it can pay big dividends to get the design correct, even if it involves spending more time or money early on.

Of course, both the designer and the design checker require the appropriate *engineering authority* to perform this work, which includes having relevant experience to help discern potential adverse issues and so address them.

One area where errors can pass through quite innocently, is when someone writes a computer program, or models something in a spreadsheet (which is by itself an extremely powerful design tool). The validity of the program or spreadsheet needs to be independently checked and validated, using whatever methods are deemed appropriate. After all, once a program starts being used, people will assume it will always give accurate answers (and it may also be used for other projects).

Sometimes even with an independent check, errors might creep through in the design, but the expectation is that the chance of this happening is extremely small.

A NOTE ABOUT COMPUTER PROGRAMS

There are a number of OHW design computer programs that were written to aid in the production of various design details. These programs are listed in *Section 8.3*.

On the positive side, these programs can save an enormous amount of design effort and time, provide a higher level of accuracy, and deliver the information in a familiar output. And in doing so, this can give consistent results, which is a good outcome.

However, the one (seemingly constant) criticism of computer programs is that they can remove, from the operator, any understanding the "mechanics" of what's actually being calculated. After all, there's no need for them to understand what's going on – it's all handled by the computer program.

It is unfortunate that this potential ignorance, in turn, means that sometimes input to the program can be erroneous without being questioned by the operator. Also, any error or warning messages issued by the program may not be properly understood and/or acted upon.

Having written most of the listed programs in *Section 8.3*, I think I have a good understanding of their operation and the origins of the calculations involved. And I can fully appreciate their time-saving nature because I've experienced the tedium of manually calculating the relevant

equations over and over again (that is, until the idea of a suitable computer program sprang to mind).

So, my suggestion here is that each designer should ideally work through the equations from time to time, just to get a working appreciation of what's actually being done by the computer program. If this is done, I think it can better equip designers in future and yield big dividends in many ways.

OHW Design Drawings

The design of an OHW project often involves the development of many design drawings to encompass the entire changes being proposed.

For an idea of the types and format of the various OHW design drawings, refer to *Section 10.1*, *Appendix "A" – OHW Design Drawing*.

A typical design drawing includes the following aspects:

- *Title Block* – This gives important details of the project including its subject *title* (such as "Switch Arrangement"), unique *drawing number*, drawing *scale/s*, drawing *references* (where applicable), its *status* (e.g. "For Construction"), and drawing *revision number*. The revision details are one of the more important pieces of information on the drawing.
- *The design details* – This is the main purpose of the drawing – to communicate the proposed arrangement or changes in a visual way. In this regard, it should show various views of what the final product looks like, and describe how to get there. (It may also be necessary to provide one or more "Detail Views" for a closer look of the action.) Pointers to the item numbers (per Bill of Materials) should also be included.
- *Bill of Materials (BOM)* – This provides a simple and logical sequence of *parts* needed for the design's construction, including *material descriptions* and their *fitting numbers* or other *reference* (if applicable), *quantities* needed, and a *drawing reference* for more details of the part.
- *Notes* – The constructor needs to understand these important notes in order to build the design.
- *Scale/s* – Where one or more measurement scales have been used, it's extremely helpful to include a scale and its length marked off so that it can be verified on site with a scale rule.
- *Revision details* – this captures some of the history of changes made to the drawing over its life, in line with its revision letter or number. Important for later reference.

Control of OHW Design Drawings

Figure 608 is a sample of a *Control Sheet* for Design Drawings in a typical OHW project. This sheet format was set up to help satisfy certain requirements of the QA system at the time. The sheet is generated and kept up to date by the OHW designer in charge of the project.

The top of the page provides a summary of the project, including any Job Number that links to the specific project.

Construction of the OHW

One of the most important outcomes is that the OHW is built according to the requirements set out in the various design drawings for that project. It can be sometimes frustrating for a designer to see OHW being built in "autopilot" mode, for example, where the constructors assume that the requirements for next run of OHW are the same as the previously-installed run, with little reference to the actual design outcomes needed for that new run.

Any resulting variations (errors) to what's built either need to be corrected in the field, or if deemed acceptable by the designer, then the design needs to change – either way needlessly costing lots more $. Refer to *Section 2.5.12*, *Construction of OHW Infrastructure*.

Register of Drawings

Project : Strathfield Junction
Aspect : OHW Drawings
Version : 1.9

RailCorp - Electrical Design
Job No. : A/03/365

Drawing / File No.	Version	Date	Drawing Title	Comments
Layouts				
~~OH003F012.dgm~~	~~2.0~~	~~15/11/2005~~	~~Strathfield Junction OHW Upgrade Project - Continuous Layout~~	~~1:500~~
~~Up & Down North Subs.dgn~~	~~2.0~~	~~15/11/2005~~	~~Strathfield Junction OHW Upgrade Project - North Junction - Continuous Layout~~	~~1:500~~
A1/89617 Sh. 31	C	26/02/2010	Central to Lidcombe OHW Layouts - Strathfield	
A1/89617 Sh. 32	B	26/02/2010	Central to Lidcombe OHW Layouts - Strathfield	
A1/89617 Sh. 33	D	26/02/2010	Central to Lidcombe OHW Layouts - Strathfield	
A1/89617 Sh. 34	E	26/02/2010	Central to Lidcombe OHW Layouts - Strathfield	
A1/89617 Sh. 35	C	26/02/2010	Central to Lidcombe OHW Layouts - Strathfield	
A1/88373 Sh. 1	F	26/02/2010	Strathfield to North Strathfield OHW Layouts	
A1/88373 Sh. 2	G	26/02/2010	Strathfield to North Strathfield OHW Layouts	
Profiles				
A2/90236	B	29/07/2006	Strathfield Flyover - Main Suburban Line - Bridge Profiles	Drawing signed at "B" revision.
Brige Arrang'ts				
A2/90237	B	18/07/2006	Strathfield Flyover - Main Suburban Line - Arrangement of Fittings	Drawing signed at "B" revision.
Switching Arrg'ts				
EL0232991	B	16/12/2004	Location MS11+647 - Switching Arrangement - Down & Up Local	
EL0232990	A	29/12/2004	Location MS12+494 - Switching Arrangement - Down & Up Local	
EL0237888	A	19/07/2005	Location MS11+976 - Switching Arrangement - Down & Up Sub, Down & Up North Sub - Sheet 1 of 2	
EL0237889	A	19/07/2005	Location MS11+976 - Switching Arrangement - Down & Up Sub, Down & Up North Sub - Sheet 2 of 2	
EL0191934	A	21/08/2006	Location MS12+140 - Switching Arrangement	
EL0444191	A	22/09/2006	Location MS12+108 - Switch Arrangement - Sh. 1 of 2	
EL0444192	A	22/09/2006	Location MS12+108 - Switch Arrangement - Sh. 2 of 2	
EL 0205512	A	27/08/2007	Location MS11+969 - Down Main - Switch Arrangement	
EL 0234437	A	30/08/2007	Location H12+212 - Down & Up North Main - Switch Arrangement	
EL 0372318	A	3/03/2009	Location MS11+512 - 6 Switch Arrangement - Sh. 1 of 2	
EL 0372319	A	2/03/2009	Location MS11+512 - 6 Switch Arrangement - Sh. 2 of 2	

Description of Changes :

Version	Changes
1.0	0232991 - Switch arrang't MS11+647 added. KF 22/11/04
1.1	0232990 added and 0232991 updated to rev. B. KF 29/12/04
1.2	Drawings 0237888 & 0237889 added. KF 22/7/2005
1.3	Continuous OHW Layouts added (OH003F012.dgm & Up & Down North Subs.dgn)
1.4	Drawings A2/90236 & 90237 added at "B' revision. KF 10/8/2006
1.5	Drawing EL0191934 added. KF 22/8/2006.
1.6	Drawings EL0444191 & 192 added. KF 28/9/06
1.7	Drawings EL 0205512 & EL 0234437 added. KF 30/8/2007
1.8	Drawings EL 0372318 & 2319 added. KF 3/3/2009
1.9	Discrete Layout Sheets A1/89617 Sh. 31-35, A1/88373 Sh. 1-2 brought back from continuous Layout models. KF 8/3/2010.

Issued to :

Section / Title	Name
RailCorp - Electrical Design (Originator)	Ken FitzGerald
RailCorp - Design Delivery Manager	
RailCorp - Construction Manager	
RailCorp - Electrical Construction	

Note: This list identifies the current issue of the above documents/drawings. Please destroy all superseded copies.

Figure 608 - Sample of Control Sheet for an OHW project

The prime purpose of this sheet is to *list the set of all relevant Design Drawings* that should be referred to during the construction of the project. This information can be progressively built up as various stages are reached in the project.

This is done to help ensure that anyone building to the information can know the current *revision* of each drawing prior to using that drawing when constructing or altering the OHW.

It also helps people know what *total information* is available for that project, that needs to be referred to during its construction.

The drawings are structured into the various OHW categories as described in this document, i.e. Conductors, Support & Registration, etc. (see front cover page of this document). Taking this structured approach should help to ensure that there's no missing information for constructors and others to refer to. (This may include drawings like Temperature/Tension Charts, etc.)

A brief *summary* of the history of the development and issue of the drawings is included near the bottom. This can be handy when you need to look back to identify when certain drawings were changed.

Lastly, a *distribution list* is also at the bottom, which identifies all parties that require this information (names have been omitted). Note that this could/should include the District where the OHW changes are being made (for their information and feedback if needed).

When the project is completed, the Control Sheet should have a complete list of all signed-off drawings that the project was built to, and this should be given to the District at hand-over.

The advantage of this approach is that this single sheet can help control the whole OHW design process of the project. The sheet should be stamped "Controlled" (in Red ink) and entered into the QA system for that project. In this example, this control sheet is *Version 1.5*. And the stamped sheet should then be sent (emailed) to all listed recipients.

In this way, the multitude of individual signed-off design drawings do not then need to be stamped "Controlled", since their individual status is covered by this single control sheet.

Note that some drawings can be planned to be produced by listing them in this sheet, even if a drawing numbers haven't yet been allocated. The "OHW structure" headings should help to flush out all the drawing types needed, which can help to manage the project, especially at the early stages.

Similar *control sheets* should be set up for controlling other types of information, including:

- *Loading Diagrams* (for issue to Civil design),
- *Drop Vertical Length & Position Tables* (Civil Design),
- *CCALCs* (in wire runs),
- *OHW droppers & in-span feeders* (in wire runs), etc.

The information within these sheets would then be ordered in some rational listing, possibly distance-based wire runs (heading away from Sydney).

So, in many ways, this is an extremely useful sheet to help *manage* an OHW design project.

5.1.29 OHW Design at Turnouts

Standard EP-08000008-SP, "Crossover & Turnout OHW Geometry", gives guidelines on how best to design the OHW for these crucial pantograph interface areas, allowing pantographs to reliably pass between one OHW run and another (and often quite abruptly). *Figure 609* shows some OHW at a relatively simple turnout situation.

Turnouts allow a train on one track either continue through on this track or be diverted to another track (if the direction of train travel will allow it). This other track can be a siding, another main track or a crossover to another track (which has a turnout at each end).

The wiring of turnouts can be somewhat tricky to design and also then to implement in the field.

Special care needs to be exercised at the various "forking-in points". These are locations where the edge of a pantograph first picks up the diagonally oncoming contact wire of the adjacent wire run (from the side of pantograph).

Refer to *Figure 610*, which shows a sequence of how the pantograph travelling on the crossover track *takes up* the adjacent contact wire on the main line track it's approaching.

Figure 609 - OHW servicing a typical track turnout

The *forking-in point* is the location (or zone) where a lot of contact *side wear* can take place. Some small amount of wear can occur even if the OHW is properly designed and installed, so it's absolutely critical to take time to set it up correctly in the field.

The horns of a pantograph are made from stainless steel and unfortunately this hard metal can gradually abrade a copper contact wire, notably if the wire has to touch the horn and then slide up and onto the top carbon strips (and this action is performed repeatedly over the life of the equipment). Sometimes this abrasion wear to the side of the contact wire can be rapid, especially if the geometry is not correctly designed and/or installed. Such wear must obviously affect the pantograph as well. (This type of diagonal wear on the contact wire was illustrated previously in *Figure 55*.)

If the situation cannot be improved through better alignment, then further wear on the contact wire can be prevented by installing a sacrificial *wear strip* – refer to *Section 3.1.13* for more details. The location of such a wear strip in a typical situation can be seen in *Figure 610*.

Also, it is important that any contact clamps (such as in-span feeder clamp, sliding knuckle clamps etc. which grip to the top of the contact wire), *must not be located* on the adjacent contact wire in the immediate vicinity of the forking-in points, as these clamps could otherwise be snagged by the diagonal horn of a pantograph as it transitions to this next wire. Also, dropper bottoms installed with a cup head bolt should have the cup head facing the crossover, again to help prevent the pantograph abruptly striking the long exposed threaded part of the bolt.

It turns out that the overall width of the top flat surface of a pantograph is quite similar to the distance between the rails of a track (track gauge is 1,435mm).

So, this can help get a quick appreciation of the location of various forking-in points in any turnout situation, i.e. the point where the contact wire crosses the rail of the adjacent track in plan view.

Of course, this does not take into account any vehicle dynamics and other tolerances (which are included in the pantograph gauge). These imperfections have the effect of requiring the forking-in point to be more of a forking-in *zone* (see the magenta hatch zones in *Figure 610* and *Figure 611*). Nor does it take into account any contact wire horizontal offsets due to track superelevation (if it exists). So, this approach is only approximate.

With the old *fixed-anchored OHW*, the common approach at a crossover seemed to be to run both contact wires together at the same level, resulting in a "flat" arrangement (or "flat knuckled"). See *Figure 109* for instance. This configuration was probably essential as the contact tensions changed dramatically with temperature (which is a particular problem with the hot / slack tension conditions). And extra care was needed when crossing the contact wires – see *Figure 113*.

In *regulated OHW*, where the contact tension remains relatively constant, the approach is typically to have the crossover or turnout contact wire crossing about 30mm to 50mm above the main line in-running contact, provided the train speeds are relatively slow.

In this case where the wires cross, a *sliding knuckle* is installed. Essentially, this helps limit the relative vertical movement of the main line contact wire as the uplifting pantograph passes through on the crossover track and into the main line track. It is essential that the 2 sets of wires *move up or down together* in the forking-in area. This situation is shown in *Figure 610*. See *Figure 112* for the standard arrangement and *Figure 111* as an example. In this way the 2 wires are mechanically linked (as far as any vertical movement is concerned) without restricting the wires to move longitudinally as the temperature changes. This relative longitudinal movement can be around 1m, and theoretically up to 2m under temperature extremes. (The 2m extreme can happen if the crossing location is near the end of 2 long tension lengths, with tension regulators installed nearby, although it's unlikely for one of the runs to be this long.)

For high-speed turnouts (higher train speeds), or where the track crossing angle is steep (e.g. at a diamond crossover), a *flat* arrangement becomes almost essential, e.g. *Figure 118* and *Figure 119* (standard arrangement at a diamond crossover). Otherwise there would be rapid side wear on the contact wires at the various forking-in points. In any case, they may still require wear strips, depending on any evident wear (or install as a preventative measure).

At turnouts it's important to install both the main line and crossover *catenary supports*: *a) close to the turnout*, and also *b) close to each other* in this crucial area. Typically, the cross-over support masts are located something like 6m to 10m into the turnout (depending on turnout geometry), and both catenary supports are spaced about 2m apart. In this regard:

a) The first aspect aligns the crossover wire to suit the oncoming crossover geometry (staggering to suit pantograph security).
b) The second aspect helps keep the 2 contact wires *at similar heights relative to each other* in this area near the forking-in point. The contact heights are then well controlled here because the catenary wires at their support locations cannot move vertically by much. (This catenary height movement comes about due to the pantograph unloading the contact wire weight from the catenary and causing it to rise – this happens the most at mid-bay but very little at locations where the catenary is supported.) Therefore, the supported contact wires also don't move vertically at catenary support locations (by a similarly small amount).

To expand on b) above, if the contact wires were allowed to move up or down by much more than about 100mm *relative to each other*, then this may jeopardise the situation by possibly allowing the lower contact wire to ride *down* the horn of an approaching (uplifted) pantograph (instead of rising up the horn), and then become tangled.

Fixed knuckles (in the fixed-anchored system) and *sliding knuckles* (in a regulated system) are often installed to further help minimise (or restrict) any relative vertical movement of these contact wires in this area. This is important.

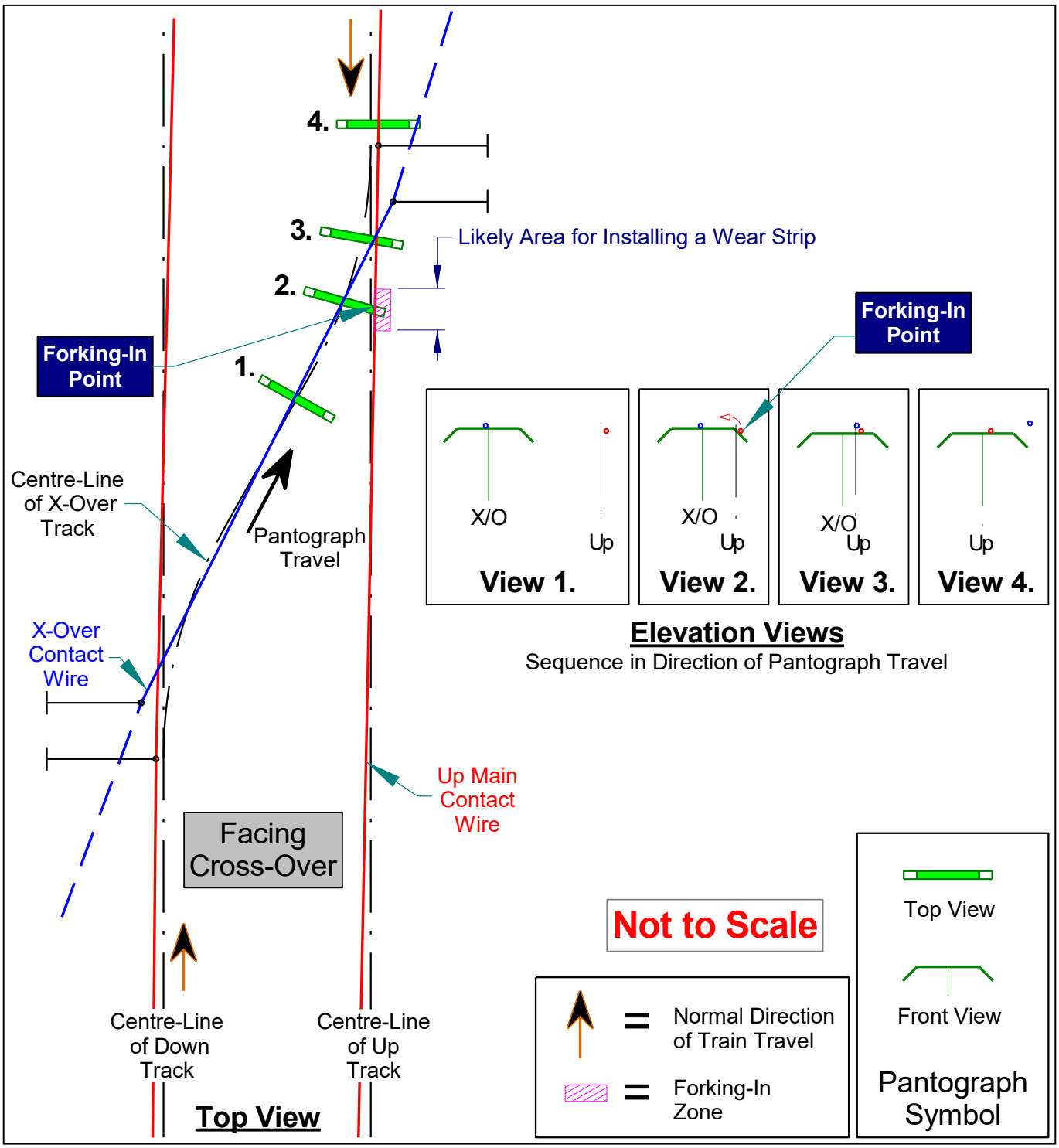


Figure 610 - Pantograph on crossover track picking up main line Contact wire

In a turnout design, there has been a policy with regulated OHW design, to always aim to *cross the contact wires* (in plan view). This is because it allows a sliding knuckle to be

installed, which ensures that both the wires at that crossing point move vertically together (trace each other), and this helps the pantograph negotiate this crucial junction area.

Figure 610 is intended to show the sequence (Views 1. to 4.) of how a pantograph horn picks up an adjacent wire (in this case the Up Main wire) at the *forking-in point*. It then continues on its way on the Up Main track. The forking-in point is actually a zone, due to imperfections such as the various track / OHW / pantograph tolerances, wind blowout at the time, etc.

Figure 611 shows where the typical forking-in points (or zones) are located for the turnouts in (1.) *Facing Crossover* and in (2.) *Trailing Crossover* situations.

1. ***Facing Crossover***.
   A "facing turnout" situation is good because it can readily provide a smooth wire transition from main line to crossover, with the main line contact wire simply sliding off the edge of the pantograph as it continues through the crossover. The worst that can happen here is some relatively minor arcing as the main line contact wire comes off the pantograph if the train is pulling lots of current (most of the power would come via the crossover contact wire).
   However, when the pantograph comes into the other main line, the horn of pantograph has to pick up the adjacent main line contact wire at the forking-in point. This was shown in sequence in *Figure 610* (described above).
   A train traversing the crossover in the opposite direction (from Up to Down track) has a similar forking-in point located on the Down track OHW (as shown in the diagram).
2. ***Trailing Crossover***.
   There are 2 cases to consider here.
   Case (a) – Pantograph on Crossover. This shows a pantograph passing through the crossover having similar forking-in points as described in 1. above.
   Case (b) – Pantograph on Main Line. This situation shows how there can be additional forking-in points for a train travelling through on the main line track (not using the crossover), *if the crossover wire is low enough to contact the uplifting pantograph*. This can happen in flat knuckle arrangements, and it can happen if the pantograph has lots of uplift as it passes this area (even if the crossover contact is at a higher static height). This latter condition can be rather nasty, because it can take place at the full main line speed, and any pantograph suddenly connecting (striking) with the adjacent crossover wire will likely cause considerable wear and/or other damage.
   Also, there may be some arcing if connection is made with the crossover contact wire and then lost as it continues at speed – the loss of connection can cause an arc if the train is drawing lots of current. (However, any resulting arcing damage probably wouldn't be as significant as the sudden impact damage described above.)

One final comment:

A "bowed" (or vertically "curved") pantograph would likely improve any adverse aspects encountered at turnouts, by virtually eliminating any forking-in issues, with the curved ends of the pantograph allowing a smoother take-up of the adjacent wire coming into running. However, Type 6 section insulators in particular, because of their widely-spaced side runners, may cause damage to both the pantograph and SI with such a pantograph shape (unless *all pantographs* were this shape and *all side runners were adjusted vertically to suit this shape*).

For more details on the "However" aspects, see *Section 6.3.2.1, A Proposed "Bowed" Pantograph Head*.

Standard EP-08000008-SP, "Crossover & Turnout OHW Geometry" has much more to say on the requirements of designing and installing OHW for turnouts.

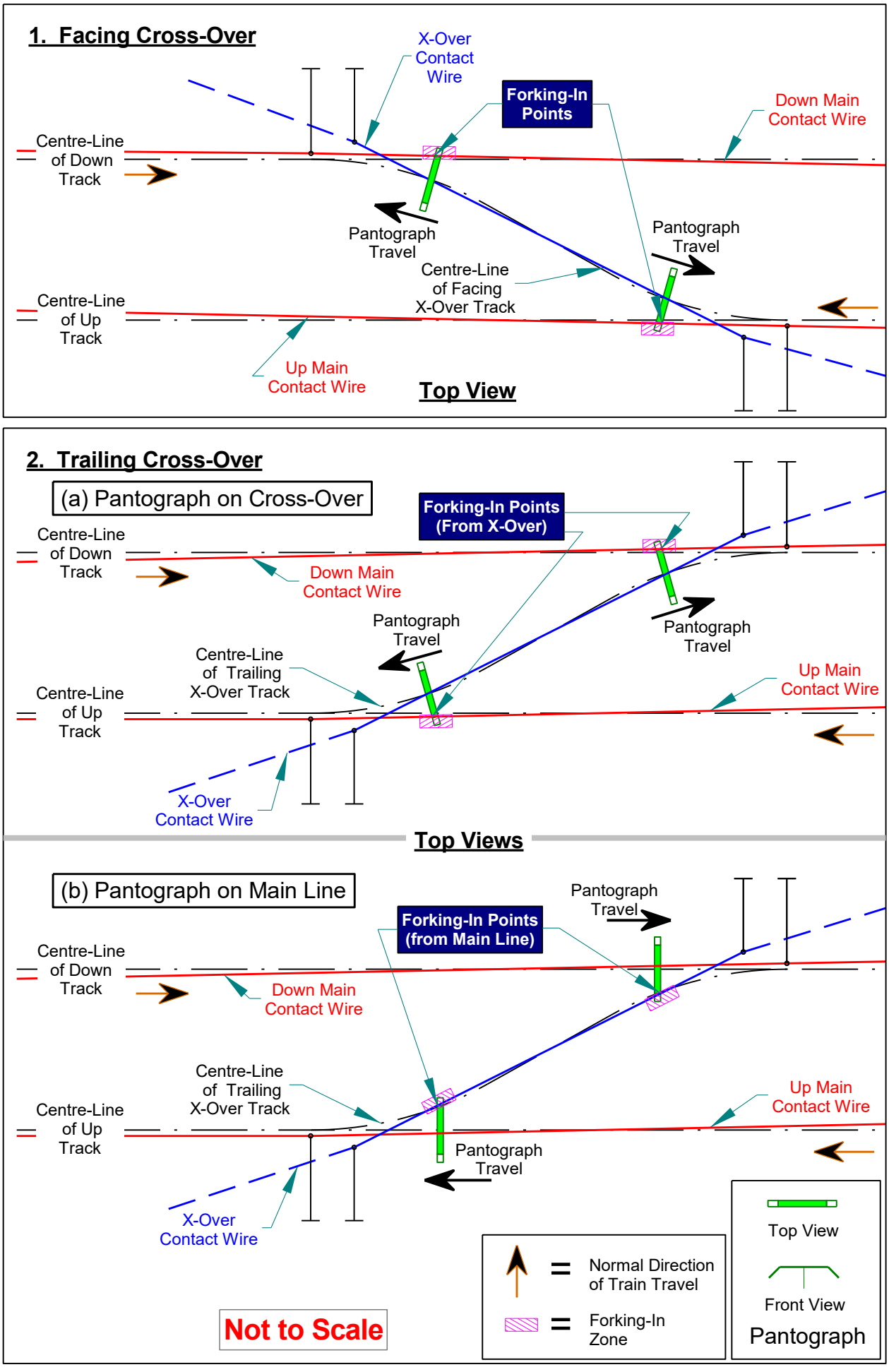


Figure 611 - Location of various "Forking-In" points

5.1.30 Drift of Regulated OHW

It may seem that regulated OHW conductors installed on a steep hill would want to drift downhill, leading to much higher tensions at the top of the hill.

However, if you look at the way the regulated OHW is supported, there is only a small out-of-balance force tending to drag the wire downhill.

OHW is supported by cantilevers installed on *vertical* masts, so that as the wire lengthens or contracts under temperature changes, these cantilevers swing *horizontally* to a new equilibrium position. Refer to *Figure 612*. The amount of wire weight supported by the cantilever is governed by the weight of the OHW conductors between the 2 adjacent *catenary low points*. Cantilevers swing until conductor tension equilibrium is reached – when the horizontal component of the catenary tension is the same in each adjacent bay at the support.

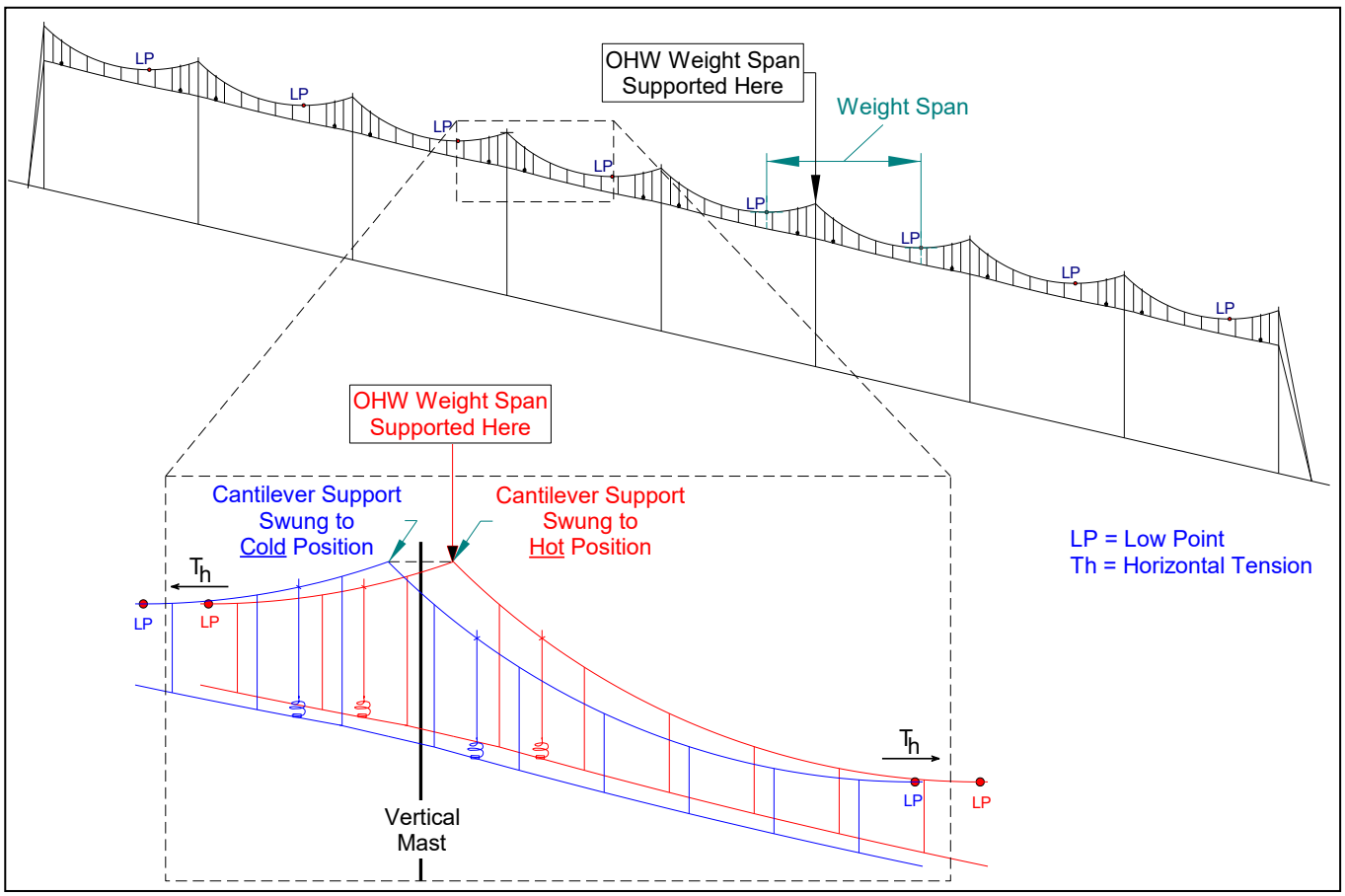


Figure 612 - Horizontal Cantilever swing moves OHW horizontally only

So, all that happens is the catenary low points move horizontally, i.e. the catenary wire doesn't move downhill. Cantilevers swing left and right (not up and down) in the process.

The weight of the contact wire is transferred to the catenary wire by the droppers, so this has no effect on this issue.

There may be only a small out-of-balance tension component where the wire goes off to anchor, that can affect the conductor tension in a small way.

Note:

If the masts were installed *perpendicular* to the inclined track (i.e. leaning downhill), then the catenary height would change with wire movement. In this case, there would be a big tendency for the OHW to drift downhill, resulting in significant wire tension differences between those at the top and those at the bottom of the hill. But this is not the case – the

masts are vertical, and this is one main reason why they have to be vertical in the longitudinal direction. (Masts can still have rake, which is an incline laterally away from the track being serviced. In this way, loading the mast should make the mast effectively closer to vertical.)

5.1.31 The Role of Survey

In the OHW design process, whether it be for the construction of new OHW or for alterations to existing, having accurate survey information that identifies and locates specific nominated items (in 3 dimensions) is absolutely essential. Some of this information can be generated on CAD, notably the *design* alignment position of track.

Items of most interest include:

- The TCM (nail) in an OHW structure,
- The underside of an OHW portal bridge,
- Location of drop verticals (face of DV to track/s),
- Location of beams and other potential support points or impediments on overline bridges,
- Track position details (both horizontal and vertical, and both design and actual on the day),
- Tunnel cross-sections at nominated locations,
- etc.

Knowing the position of these items is especially important when OHW infrastructure needs to be built to "within tolerance" of its design position (referencing the *design* track position).

The challenge for an OHW designer is to specifically nominate the items required for survey – complete and without ambiguity – because it's costly (in terms of time and $) to get the survey performed in the first place, and no surveyor really wants to go out again to pick up something that was missed or misinterpreted. (I think I must have really annoyed some surveyors over the years in this regard!)

3 DIMENSIONS

Complete survey gives a 3-D location of a nominated item, i.e.:

- ***Eastings*** (E) – How far *east* the item is from a reference.
- ***Northings*** (N) – How far *north* the item is from a reference.
- ***Relative Level*** (RL) – This is a *height* relative to some horizontal datum level.

The reference point or datum level itself is not important, because we rely on the *differences* between the various references to get the information we need to progress the design. For instance, the "Centreline of Track to Face of Mast" horizontal distance (needed for input into the CCALC program for generating OHW cantilevers).

Example 1:

The design RL of a track at 2 different places tells how much the track rises (or lowers) over that distance.

Also, the difference between RLs of the TCM on a mast and the underside of portal bridge gives the height of the portal bridge from nail, which is fed into the CCalc program.

Example 2:

The E & N of the TCMs on 2 successive masts gives the (horizontal) distance between these structures. The distance D between Point 1 (E_1, N_1) and Point 2 (E_2, N_2) is given by:

$$\rightarrow \text{D} = \sqrt{(E_2 \quad - E_1\ )^2+(N_2 \quad - N_1\ )^2}$$

SURVEY COORDINATE SYSTEMS

As I understand it (not being a surveyor myself), there are basically 2 types of survey reference systems in use in Sydney's train network, namely "ISG" and "MGA".

ISG

This stands for "Integrated Survey Grid", and applies to New South Wales. It's an older system that is being replaced by the MGA system (below).

I could be wrong here, but you can tell if it's the ISG system if the Northing starts with something close to a "1" (million), e.g. on the OHW Layout, North Sydney Station has a Northing of 1,254,000.128 (metres).

MGA

This stands for "Map Grid of Australia", and applies to all Australia. MGA is replacing the older ISG system, and is more relatable to Global Positioning Systems (GPS), e.g. on some GPS receivers you can select a readout in MGA coordinates or in Latitude/Longitude.

Again, you can usually tell if it's the MGA system if the Northing starts with a "6" (million) or thereabouts, e.g. on the OHW Layout, Chatswood Station has a Northing of 6,258,700.456 (metres).

Distances given by survey are down to the millimetre, which provides enough accuracy for any OHW item to be located and dealt with in a design.

SURVEY TOLERANCE

Important measurements should have a tolerance, and this includes survey distance measurements. I think (from memory), survey errors of only about 5mm or less can be easily provided, but this depends on the importance of the situation being designed, with higher resolutions possible if you ask.

In the past, surveyors often used a *target* which rested against the thing being measured. It needed to be large enough to be seen from a distance through the surveyor's *theodolite* (which measures horizontal and vertical angles accurately).

The target is typically round (and includes some painted cross-hair pattern). Ideally, any uncertainty in this measurement should be taken into account in the provided survey readings. But this needs to be confirmed, otherwise the accumulated measurement error (when adding other types of measurement errors) can cause problems with the design of the OHW, particularly where pantograph and rolling stock clearances are involved.

No doubt there are probably more modern ways of locating and measuring specific target points which results in errors (less than 1mm?).

I know that *survey cloud scanners* are becoming more popular these days for providing a convenient 3-D model of infrastructure, including the continuous shape of tunnel linings, etc. – very handy for designing in 3-D ! However, I'm not sure of their absolute accuracy and how long it takes to get the level of precision measurement suitable for OHW design work.

EXAMPLE OF IMPORTANCE OF SURVEY

A good example of the necessity for accurate survey is given back in *Figure 268*, which shows a survey mark – a cross-hair and the number "1" in black ink on the tunnel lining at a proposed support & registration location on the Airport Line.

This marked the exact *design* location of the centre of a catenary support bracket to be installed there. Later, the bracket's *actual* installed position (in terms of its Easting, Northing and RL) was subsequently fed back to design for validation and for processing in the computer program "T-Calc", for determining the exact catenary height and stagger that would result at that location. This approach meant that the OHW could be installed well before the track was even laid, but it required the track to be built to its agreed design position and within its tolerances.

There would have been about 2,000 such marks for the various OHW support & registration brackets and anchor brackets throughout this tunnel. (There were usually 4 marks – "1", "2", "3" & "4" – at every OHW support & registration location for the 2 tracks.)

This required a computer program to be written to process the huge amount of survey information, in order to provide meaningful, detailed and accurate construction instructions to build the OHW within its various tolerances.

The system worked well! But it relied heavily on accurate survey work.

5.1.32 Access & Right-of-Way

Just a comment that, unlike HV Aerial Lines (Transmission Lines) which can be located just about anywhere and are not restricted to being located next to the rail corridor, generally there are no special needs regarding the provision of access & right-of-way for OHW.

The OHW is, for the most part, installed over the train tracks within the rail corridor, and any issues of gaining access & right-of-way to the tracks is a Civil discipline responsibility.

5.1.33 Suggested Areas for Improvement

There are a number of areas that I consider could be improved and bring about savings of one form or another. They are listed below for consideration, but would need to ultimately be endorsed by Standards.

STANDARDISE ON DESIGN TEMPERATURE OF 25°C

See *Section 3.1.0.5*, *Adopting a Higher Design Temperature*.

INSTALLATION OF FEEDER & POTENTIAL JUMPERS

From what I've observed over the years, the installation of FJs and PJs in regulated OHW seems to be somewhat subjective in 2 regards:

- The *length* of the jumpers needs give them sufficient *depth* to allow for free movement of both attached catenary wires (most often moving in opposite directions), without restricting their longitudinal movement at temperature extremes, or causing "birdcaging" of this jumper wire or its fatigue over time.
- The positioning of the 2 cross clamps needs to also be set with the correct offset for the temperature on the day of installation. This offset should also be checked later on by maintenance staff every now and then as required. A clamp placed out of position, may hinder the free relative movement of both catenary wires at one extreme temperature.

See *Section 3.1.12.5*, *Jumper Installation Offset* for more information.

TWIN CONTACTS SHOULD BE SPACED 50MM APART

In the standard OHW System (No. 2) – the single catenary / twin contact system – the horizontal spacing between twin contact wires should ideally be *set at 50mm* throughout the wire run (not 150mm), and supported by *delrin bar droppers*.

There's sometimes much confusion when some bays have the current standard 150mm spacing and others have the reduced 50mm spacing (which is required for leading into an SI or before going under a low bridge, etc).

I think the only slight benefits for having 150mm spacing are that:

- It can provide slightly less wear on the pantograph carbon strips, as one wire ventures further out towards the end of the pan to wear more carbon strip there (but still within limits).
- It can also help to a degree in terms of pantograph security, by having 1 of the 2 wires located 75mm (instead of 25mm) closer to the centre of pantograph from the staggered position throughout the bay. In this way, if the other wire came off the pantograph somewhere in the bay (for whatever reason), this wire may be able to still control the pantograph uplift. (This is a 50mm improvement.)

However, the 50mm spacing, with delrin bar droppers, gives the following benefits:

- It forces the pantograph to run on both contact wires throughout the run when in-running (the delrin dropper allows free rotation which causes both wires to be equally in contact with the pantograph, with each offering the same downward pressure against pantograph).
- No mix-up confusion in design (or construction) whether some bays should be 150mm & others not.
- Contact termination clamps arrangements for section insulators are more suited to 50mm spacing.
- 50mm spacing is necessary for passing under low overline bridges and inside tunnels.

However, this would require some design thought where the wire goes out-of-running to a pennant insulator, often terminating on a plate with 150mm spacing. But this is only a small problem to be resolved.

An alternative of implementing the 50mm spacing, by using *independent droppers* (spaced 1m longitudinally apart), can unfortunately allow the contact wires to clash together when train power is suddenly applied, causing some concern as to what's happening (although no damage is likely). This situation ought to be avoided if possible, and that's why delrin droppers are so suitable, as they prevent any such clash (see *Section 3.1.2.5*, *Twin Contact "Clash" with Heavy Current*).

There are so many advantages to the delrin bar dropper arrangement. See *Section 3.1.3*, and particularly *Section 3.1.3.5*, *Twin Contact Dropper Problems*.

The twin catenary systems would remain at 150mm contact spacing.

OIL IN TENSION REGULATOR PULLEYS

Grease is currently packed inside the tension regulator pulleys, but this can dry up and become ineffective in time. And moisture ingress past old seals can accelerate corrosion within the bearing.

If an oil bath were to be introduced instead, this would ensure the roller bearings received their proper lubrication, and this would reduce the likelihood of the internal corrosion mentioned above.

Importantly, it would give tell-tale signs of a problem, if oil was seen leaking from the bearing, whence corrective action could be taken.

At the moment, the integrity of the grease inside the bearing is unknown (hidden), until it's dismantled. There are usually no external signs of any problem.

Indeed, the only way to check if the pulleys are working properly is to see that they've rotated (but even this approach is not perfect). The next "Improvement" below talks further about this situation.

See *Section 3.4.2.5* for details of the lubrication of these bearing.

SEIZED PULLEY INDICATOR

There should be an indicator of some form installed at one end of each pulley axle to help show if the pulley is seized. For example, see *Figure 613*. This idea was mooted by somebody many years ago, but sadly nothing seemed to come from it.

If the axle indicator normally points in one direction, say vertically up, then any non-upward angle would suggest a seized bearing, prompting that pulley change-out action be taken.

I know some attempts had been taken to try to retro-fit such a system, with uncertain results. The problem is the need to fix the indicator to each pulley on the existing stainless steel shaft (which doesn't project far beyond the pulley side plates).

The implementation of such a system could bring about reliability benefits into the future.

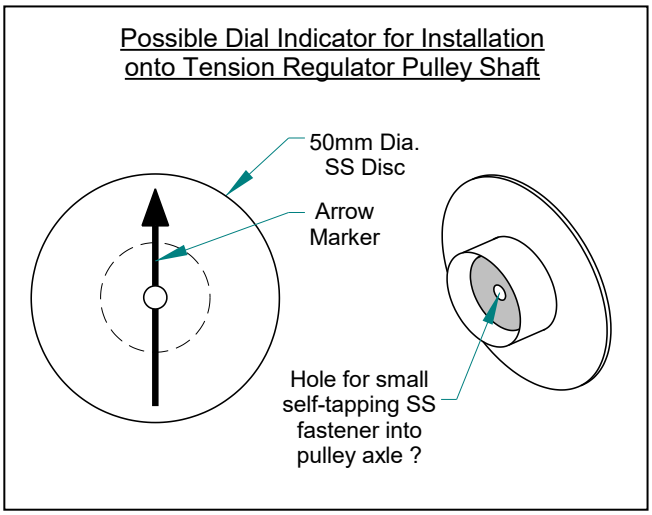


Figure 613 - Possible pulley shaft indicator

The indicator need only be installed on one side – the side most convenient for viewing with binoculars from the access track.

PERMANENT FITTING IDENTIFICATION

As mentioned in *Section 5.1.6*, all OHW fittings should be permanently labelled with their corresponding fitting number, and in some cases with their length also (which is helpful on pull-off arms). The Fitting Number could be stamped, cast, written in permanent marker, etc.

Example:

"**955/1 1,050mm**"

The position of the text should be such that it can always be seen, e.g. with twin contacts, the text should not be obscured when one arm is placed next to the other (a challenge).

This would be a relatively simple and inexpensive thing to implement on most fittings (it should be a requirement placed on the manufacturer). But it could make a huge difference to the quality of installation work and subsequent maintenance activities into the future, by removing the guesswork in the field.

This is highly relevant for the pull-off arms, since there are so many of them (1 or 2 at every registration location), and they come in different lengths (often in 50mm increments) – see *Section 3.2.0.3*, *Pull-off Arm* / *Suggested Improvement*.

SYDNEY'S "OHW FITTING NUMBER" SYSTEM

As "Commented" in *Section 5.1.6*, over the past 2 decades or so, there has been a tendency for external designers to use their own unique numbering system when generating new OHW fittings or arrangements for their project in Sydney's OHW system. There are distinct disadvantages when doing this, as already mentioned!

From the early days of Sydney's electrification, it was mandated that the *OHW Fitting Number System* – in the so-called "Brown Books" – be used to take out new fitting numbers when any new OHW fitting or arrangement was developed. In doing so, it provided a ready reference to the new equipment for everybody who had the need to know. Importantly, its history was trapped for any future requirement. There are so many other advantages in using this old reference system (it's probably updated into a database system by now).

The recommendation here is to continue to *mandate* that any new OHW fittings or arrangements, designed by any designer for use in Sydney's OHW system, should be recorded with their own unique fitting number, as per the above *Brown Book* system (or its database equivalent).

OHW LOCATION NUMBER CONFLICT

OHW structure location numbers are labelled with a "+" sign between the kilometres and metres, e.g. N123+456. This is an *approximate* kilometrage from Sydney 0km (and has been since the 1920s, albeit using the imperial measurement system in feet).

Unfortunately, this Electrical reference has been recently compromised (c. 1990s), with the track kilometrage suddenly adopting the "+" sign also, to now signify their track kilometrage, which *is* accurate (although with various "kilometrage adjustments" made along the way). This problem was brought on by the MicroStation CAD software used for designing trackwork.

While there was an initial "work-around" attempted to overcome this disparity when it was first recognised as an issue, it has probably fallen by the wayside. Other approaches have also been attempted.

There are potential operational and safety risks associated with this conflict.

See the end of *Section 5.3.3*, *A Recurring Problem* for more on this issue.

POLICY ON APPEARANCE OF ANNEALING

As mentioned in *Section 5.1.14*, a standard approach should be adopted and promulgated to help OHW maintenance staff discern if pink-coloured copper catenary or contact wire is actually genuine signs of annealing – or not – and the best way of dealing with the situation if the wire is not actually annealed.

THE IMPERATIVE TO IMPROVE

Over the past few decades there have been many external design companies that have come to help with the (often huge) OHW design burden – as new areas needed to be wired, or existing areas needed altering for various reasons (e.g. installation of new overline bridges).

With the pressure to get designs out, there is normally little or no time available to approach design work in different ways, or to come up with better equipment in some way. So, new OHW designs are often just rubber-stamped from previous designs, and any awkward problems are made to somehow fit using existing approaches and equipment.

However, I believe there needs to be some *encouragement* / *motivation* / *imperative* to bring about positive change, that benefits not just the design company involved on a project, but ultimately everyone who performs OHW design work for the Sydney network.

The main reason I've stayed in this design area is because of the wealth of opportunities to improve things – be they new OHW parts or arrangements, or processes, etc. This is where I really felt I earned my keep. Considering the degree of computer resources available to help streamline the often labour-intensive design work, there should be lots of new things happening. And yet …

I know how difficult it is now to get new designs "across the line", with so many things that now need to be ticked-off, such as risk assessments, failure modes analyses, prototype testing, other standards requirements, etc.

But big benefits can happen when new equipment or processes are developed, that can make the OHW system safer, more reliable, cheaper to design/build/maintain, etc. And importantly, *they get accepted into the Standards for everyone to use.*

Sadly, there does not seem to be much motivation to head down this path. It seems that it's easier, or quicker, or cheaper, or less risky, to just design with existing standard equipment, and to bend it to a slightly different shape to fit where absolutely needed.

Even reintroducing a *Research and Development* area would be a step forward in this sense, where new ideas can be assessed and developed further without the time/cost pressures when working on a new OHW design project.

OHW Standard Arrangement Drawings

The standard drawings that describe all the OHW kit for new electrification works, or even for changes to existing infrastructure, *need to be kept up to date* when changes take place from time to time. These drawings cover all the OHW categories listed on the front cover of this document, and are described in *Section 8.2*, *OHW Equipment List*.

Changes include the incorporation of new or improved fittings (usually affecting the "Bill of Materials"), changes to standard requirements such as clearances (often listed as "Notes" on the drawings), altered approaches to design and/or construction, etc.

Sadly, altering the standard arrangement drawings tends to be the last thing that happens when changes are brought about, because it takes dedicating time and effort to make this possible. And yet, it should be the very first thing to change, with signature approvals for its ultimate endorsement and reference for OHW construction and maintenance.

OHW & Pantograph Interaction

In my opinion only, and for what it's worth …

The physical interaction between the OHW contact wire and the train's several pantographs is crucial to the "reliable" power supply to an electric train.

But in order to help bring about such "reliability", there should likewise be significant interaction between the 2 independent groups that make decisions regarding this important interface, i.e. between:

- the Electrical Group in charge of the OHW, and
- the Mechanical Group in charge of the pantographs installed on trains.

Ideally there should be *close* and *regular* collaboration: of ideas, sharing of problems to be overcome, highlighting areas for improvement, discussing current overseas trends and how they could benefit things here, etc. And this collaboration should at least occur between the Standards and Design areas of each Group.

But this shouldn't be a person to person interaction between these groups, it should be a *people to people* collaboration.

The *sharing* of knowledge, experience and expertise – between many people involved with the standards, design and maintenance of OHW and of pantographs – should make more people aware of all sorts of aspects to do with this interface. And the information gained can be more readily spread to others, which may help overcome ignorance and false information that might otherwise exist in a huge organisation.

Issues could include:

- Causes of accelerated wear of, and wear pattern on, carbon strips.
- Causes of accelerated wear on contact wire.
- Assuring pantograph security.
- Improving the take-up of adjacent contact wire onto the pantograph head at turnouts (wear on contact wire and pantograph horn).
- Assurance of constant upward pantograph force at different contact heights and at speed (aerodynamics of pantograph).
- Improvements in ability for pantographs to trace imperfections in contact wire without causing arcing and loss of train supply.
- Investigations into the causes of OHW / pantograph incidents.
- etc.

This is such an important interface. Any *improvements* – be they incremental or quantum – can potentially bring about significant benefits to Sydney's electric traction network, e.g. less interruptions and consequent wasting of travellers' time, saving the reputation for running a reliable service, saving $$$, improved worker morale if they are better informed and more involved, etc.

This is not to say that what's been achieved until now is in any way inadequate – things seem to be working really well now. It's just that, from my experience (albeit a while back), this interaction and communication could be better.

5.2 CONSTRUCTION ASPECTS

5.2.1 Preamble

The construction of OHW or alterations to it, should only take place when an OHW design for that part of the project (e.g. wire run) has been completed by the designer/s, independently checked and approved, and the status of the relevant drawings changed to "For Construction".

There can be many stages prior to running the overhead wire, such as installing masts in the ground, but even these tasks require approved "For Construction" drawings (from Civil Design in the case of structures). The fabrication of the multitude bays of droppers and in-span feeders also requires their site-specific configuration (length & position) information to be signed off and approved by Electrical Design.

The whole point of the above comment is to strive for a high level of control over the issue of *quality* information prior to things being built. This is because any *mistakes* can have an adverse effect on subsequent safety, operations and/or maintenance of the OHW equipment into the future, which will almost certainly lead to a significant economic impact as well.

The people constructing the OHW need to have been properly trained to carry out various tasks, which includes:

- Installing the various support & registration (cantilever) arrangements.
- Running catenary and contact wires – bay by bay from anchor to anchor for each wire run.
- Droppering each bay and installing associated in-span feeders.
- Installing and setting up the anchors at each end of the wire run (and possibly midway) – this includes setting the correct configuration of the tension regulator weights for unimpeded vertical movement under the temperature extremes.
- Cutting-in and properly aligning section insulators.
- Properly configuring overlaps and turnouts where 2 wire runs come together, to ensure a smooth transition from one contact run to the next.
- Installing aerial feeding arrangements to the OHW.
- Etc.

There are so many other activities that lead up to the above tasks as well.

So, with this OHW "Construction" section, it's difficult to summarise everything in this document, and it's certainly not the intent here. As such, I provide only limited information in the following subsections.

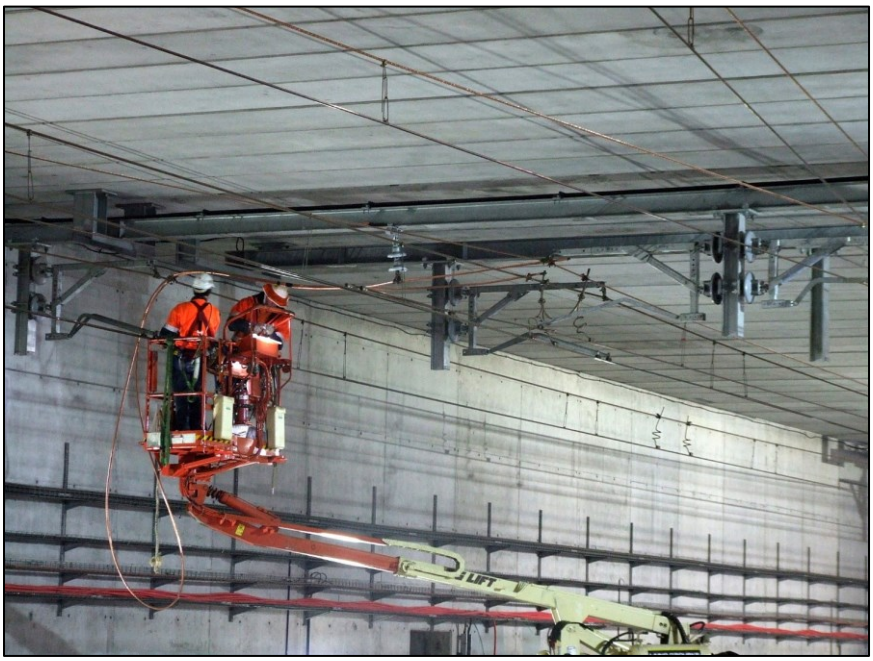


Figure 614 - Construction of OHW in the RES (Chatswood)

5.2.2 Construction Vehicles

5.2.2.1 The Old Ways

I'm not sure of the original methods of installing OHW in the 1930s and 1940s.

Later on however, and until only a few decades ago, it seems that most work was carried out on top of "wiring trains", as shown in *Figure 615*, *Figure 616* and *Figure 617* (all regulated OHW systems).

Figure 615 - Installing Twin Contact Wires from Wiring Train (Liverpool to Glenlee c. 1966)

Figure 615 shows the workers clipping up the twin contact wires to the catenary through a bay on the Liverpool to Campbelltown to Glenlee OHW Project in the mid 1960s.

There's probably no doubt about the convenience of working on a long elevated platform that extends well into the bay. The wiring train used 6 vans (I think) to provide this continuous elevated platform. As I recall, it had good lighting installed at its platform level from both side/s, with the long fluorescent lighting aimed diagonally up towards the wires, which was useful at night time and inside tunnels.

However, the safety side of this approach seems woeful, without even a handrail to help prevent a fall from the significant height of 3.9m. Those were the days!

At least it seems that the wearing of helmets was mandatory.

Figure 616 - Running Twin Contacts from wire drums (Liverpool to Glenlee)

Figure 617 - Old Method of OHW installation using the Wiring Train (Loftus to Waterfall c. 1979)

The 2 photos shown in *Figure 617* were taken in about 1979, and this is a more recent view of the wiring train in action for the Loftus to Waterfall Electrification Project (nearing its completion).

Again, it shows the convenience of the long platform, but if you accidentally stumbled, it's a long way down!

The top photo shows the gang running the catenary wire through a "Gin Wheel", in preparation for tensioning this wire run. The bottom photo shows preparation work prior to running the catenary wire from one of the wire drums (catenary and contact) in the foreground.

5.2.2.2 Recent Methods

When comparing the old ways with current construction approaches, probably the main difference is that workers in elevated positions need better protection, including to be harnessed to prevent a fall from significant height (which is 5m or so above track level).

No longer is there the convenience of a long train platform that you can walk along from one end to the other. Instead, among other machinery, there are scissor lifts – *Elevated Work Platforms* (EWPs) – with limited space for a few people to stand and work close to the OHW.

The vehicles are often "Road-Rail Vehicles", meaning that they are licensed to travel on the road, but are also equipped with special flanged wheels that can be rotated down and lock into place onto the rails of a track. This then allows them to be propelled slowly along the track under the necessary control within the rail environment.

The vehicle itself moves from place to place, although there is a small amount of room on the elevated platform to walk, both in the direction of the track and laterally (when stopped). On some vehicles the platform itself can shift laterally to a limited extent in both directions (see right-hand photo in *Figure 620*).

Workers wear a harness which is tied to the EWP to prevent a fall from height.

It's therefore much less likely that someone will fall to the track below, because it's a more constrained and controlled work environment.

Figure 618 - Construction of OHW for the Airport Line (Mascot Station)

Figure 619 - Typical current OHW Construction Vehicles (at Strathfield Station)

Figure 620 - Elevated Work Platforms in different configurations (Waverton on left, Goulburn St Viaduct on right)

Figure 621 - OHW Construction work at Epping c. 2008

5.2.3 Installing OHW

5.2.3.1 Preparation

What follows is a brief and simple explanation of the process of installing a normal regulated OHW system above a track. It may not include every activity, but gives an idea of the main tasks involved.

It starts with design. There's the Electrical Design portion, including signed-off details of the proposed OHW runs and associated equipment, and the Civil Design portion, which details the various OHW support structures (masts, portals and drop verticals) and anchor masts.

Electrical Design generates "Loading Diagrams" for each new structure to be designed (which need to be both strong and relatively stiff), and "Drop Vertical Length & Position Tables" for accurately locating the drop verticals laterally on portal bridges. This information is submitted to Civil Design for progressing their part.

Ordering the various lengths of catenary and contact wire starts early because of the long lead time required. (It's probably much longer now because the wire used to come nearby from Pt Kembla, but now comes from the other side of the world – Europe!) They need to know the wire size and lengths of the various wires (and metal type for the contact wire). These are delivered on special *wire drums*.

The track possession/s required for constructing the runs are also planned early in the piece. This likely requires the planning, by others, of alternative means of transport for travellers (e.g. organising buses to replace trains), etc. It may also require planning for alternative routes for any freight traffic affected.

The civil structures are installed and later surveyed for their as-built offsets to track and mast rakes, as well as providing the design track superelevation at each location and for each track, etc. This information is fed back to Electrical Design for generating accurate CCalcs, which are then used for gathering the specific materials together, and finally building the various OHW support & registration arrangements (cantilevers) for the wire run.

Various other components are ordered and gathered, including all the bays of droppers and in-span feeders (in sequence of installation in a bay), and section insulators, anchor arrangements and insulators, etc. If there's feeding and/or switching involved then this equipment needs to be obtained too.

Figure 622 - Left-side masts prepared with cantilevers (tied to mast)

5.2.3.2 Construction

All work on track requires the workers to be inducted onto site – to become familiar with the likely hazards of the area and the scope and nature of the work to be performed.
Workers need to also sign onto an Electrical Permit before any work can commence on the OHW. It is vitally important to know the *safe work area*. Consult the Sydney Trains *safety system* for the current specific worker requirements, which may change over time.

The following briefly describes the *basic* process for installing a run of regulated OHW.

During early planned closedowns the various cantilevers are installed on their masts or portals. Anchors (including the weight stacks) are also installed. Because the wire is not run at that stage, all equipment installed during preparation work needs to be tied back to prevent any clash with trains (or other vehicles on access tracks) when operations commence at the end of the closedown.

On the closedown for finally running the wire, the catenary is run first. All the cantilevers are swung out perpendicular to the track and locked in place with "cricket stump" fittings (or similar). The catenary is then terminated via termination insulators, to a fixed anchor at one end of the run, or to a tension regulator location which is temporarily jammed from moving.

The catenary wire is "paid out" from the wire drum as the wiring train connected to this drum slowly moves away from the anchor point towards the other end of the run. The drum has a brake which helps to maintain tension in the catenary wire during the paying-out process.

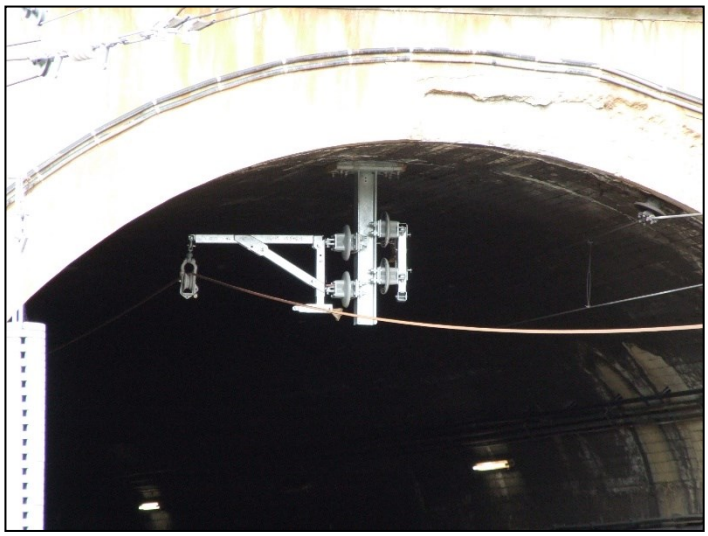


Figure 623 - Catenary wire strung through Gin Wheels

At each successive cantilever, the wire is manually passed over a "gin wheel" which is pre-installed at the bottom end of the suspension insulators instead of the catenary suspension clamp. See *Figure 623*. This frictionless wheel allows the catenary wire to settle to its natural longitudinal position without damaging the strands, when the final tensioning is later carried out. When the wire drum reaches the other end, the catenary wire is transferred to anchor through a tensioning device. The catenary is then super-tensioned to about 1.5 times its design tension for a period of a few hours (the longer the better) to help settle the wire strands and remove most of the initial copper creep. The wire is then tensioned with a dynamometer to the "No-Load Tension" corresponding to the current temperature. (See *Figure 51* further back for a typical *No-Load Tension Chart* for a fixed-anchored OHW system.)

When required, the catenary is finally terminated, allowing the weights to be released and the wire has its final (regulated) tension. If needed, the fixed mid-point catenary anchor is set up.

The process is repeated for the contact wire/s, but now the wire is progressively installed onto small rollers connected to the bottom end of the droppers. (There may be only a few droppers needed in each bay for this process, just to hold the wire in the air.) At each successive registration location, the contact is temporarily attached to a pull-off arm or equivalent, to help control radial load on this wire, especially around track curves. Again, the contact wire is anchored and then super-tensioned to remove most of the initial wire creep. It is then finally connected to the functioning tension regulator weights via the termination insulators.

Figure 624 - Installing Twin Catenary / Twin Contact OHW on Sydney Harbour Bridge, 2011
(Photos: Steve Corbin)

At some stage the various other fittings are installed (sometimes termed "jewellery"). This includes "clipping up" all droppers, installing in-span feeders at their recommended locations in each bay, adding sliding knuckles at turnouts (if required), installing any pennant insulators, FMP catenary-to-contact bridle wires and section insulators, and establishing any feeding/switching arrangements.

Figure 625 - Removing the old OHW

Any "OHW Rebuild" works requires the old OHW equipment to be taken down and removed from site (and ideally recycled where possible). See *Figure 625*.

Refer to *Figure 626*, showing the use of a "Chain Block". I understand this is also referred to as a "Come-Along" or even "Tractel" (which is a commonly used commercial name for such a device).

These devices are used:

- To *apply tension* to a catenary or contact wire, or
- To slowly *control the position* of a catenary or contact wire whilst under tension.

Figure 626 - A Chain Block in use

5.2.4 Checks Performed After Construction

The quality of the OHW and its installation needs to be checked before electric trains can begin to run. There are a number of aspects to this:

- Checking the equipment for correct installation,
- Checking for correct electrical and mechanical clearances to nearby surroundings, and
- Checking that the OHW conductors are within their stipulated tolerances to track (they need to run electric trains after all

This work includes confirming that all pins and split pins are securely in place, various fasteners are tight, the insulators are correctly orientated, there are no kinks in the contact wire, the wire is correctly aligned at turnouts and overlaps, etc.

One of the most important checks is that the contact wire is correctly positioned – stagger and height – above the track (ideally within tolerance of the design position), so as to assure pantograph security. However, this can be a bit tricky – see next section.

5.2.5 Checks for Runnability

The most important measurement checks to perform after installing or adjusting any OHW are the ***contact stagger*** and ***contact height*** at each support and registration location. Again, it's the contact wire that's important for interfacing with the train's pantographs.

The contact stagger and height should both be within their respective tolerances of the design values for that registration location. But the mid-bay stagger is also important.

However, there's a complication with measuring heights and staggers. (*Note:* this might still remain unresolved?)

Figure 627 - OHW inspection after construction (Goulburn St Viaduct)

The OHW is designed to a *"design" track position* at each support & registration location, and the OHW should be installed within tolerance of the designed wire position – both horizontally (contact stagger) and vertically (contact height). If this has been confirmed at each support and/or registration location, then the design should work. This (in an ideal world) should ensure the integrity of the OHW in terms of pantograph security and height clearances to the top of train.

However, the measurements most often taken in the field are to an *existing track*, which can be out of place in terms of its *horizontal position*, its *vertical height* and amount of *track superelevation* at that point (3 aspects). See *Figure 673* later on.

To try to help control this situation, in addition to the normal *Cantilever Construction Sheet*, the CCalc program has the ability to print out a *Construction Check Sheet* for the wire run.

This sheet gives a horizontal and a vertical distance from the reference point – the track control mark (TCM) which is a reference "nail" installed and surveyed in the mast or portal leg. Refer to *Figure 628*, dimension "**H**" and "**V**" (in red, and referenced to the closest contact wire of the 2).

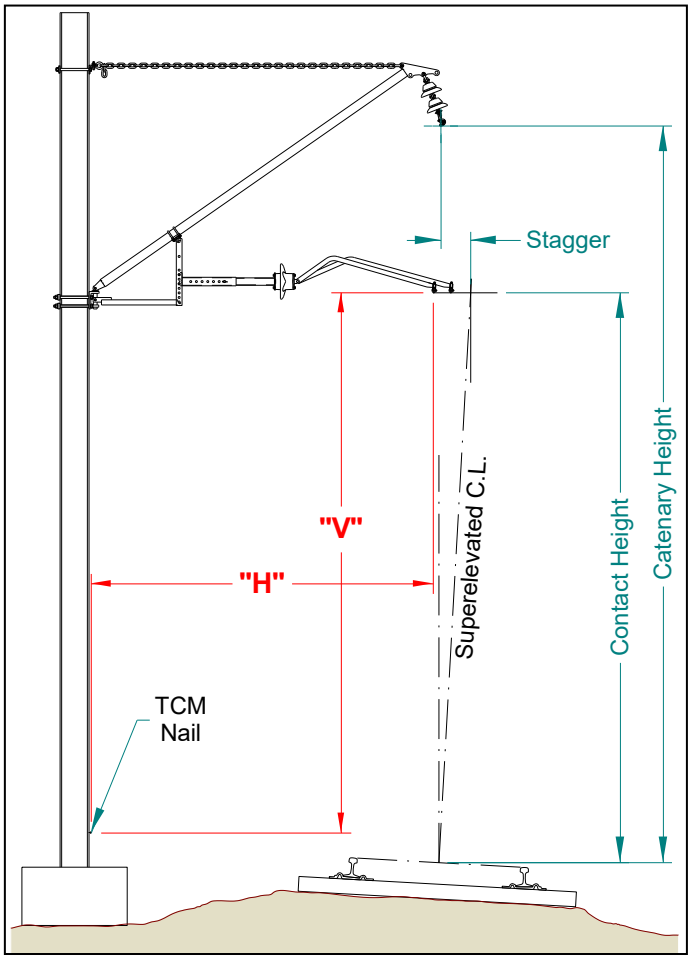


Figure 628 - Contact wire check distances

These measurements are to the contact wire (or the closest wire in case of twin contact). This then locates the *design position of the contact wire* in space, irrespective of where the track actually is. Note that the OHW could be for the 2nd or 3rd track over, which can make things a little tricker – survey could certainly help measure the distances accurately in these situations.

The intent here was to measure the actual distances from the nail to the contact wire, both horizontally and vertically, and compare these values with the value based on design. If the measurements are within their tolerance (typically ±50mm), then the contact wire is considered to be spatially in its design position and it shouldn't need any adjustment.

Figure 629 - Measuring Heights & Staggers

This approach does not involve the existing track position, and *this is the complication*, because it still needs to be runnable (to be reliable)!

In this situation, if the track is within its stipulated 3 tolerances, then all should be well, because these tolerances are accounted for at the pantograph head.

However, the situation gets a little more complicated when measuring the "Mid-Bay Stagger" which is a measurement to confirm that the contact wire, at that less well-controlled location, is in a suitable static position to ensure pantograph security under windy conditions. For long bays, the stagger should be something close to zero here. But for shorter bays, the mid-bay stagger may be much higher (e.g. 150mm) and still be OK (as per the design).

The problem here is that the track position that this stagger measurement is taken from is to the *existing track*, which could be out of its design position (but hopefully should be within its 3 tolerance figures). Unfortunately, unlike the support & registration location, there's no surveyed reference "nail" at mid-bay that tells where the track should be.

Figure 630 - Checking the runability of a newly installed Type 6 SI

Realistically, if the OHW was designed correctly to ensure pantograph security, and it's been installed within tolerance, then the mid-bay stagger should take care of itself. In the real world however, if the track is out of tolerance anywhere, then this should be taken into account and local decisions made to help with the immediate runability of the system when power is turned on. You can tell if the track is outside tolerance at the support locations, but you can't at mid-bay (unless there's a structure nearby used for other OHW).
I understand this is why measurements are made to the existing track and adjustments made based on this.

The potential problem here is that, if adjustments are made to the OHW because the track is not in its correct position, when the track is finally corrected, the OHW may then be out of tolerance to the track, and it should likewise be adjusted (ideally back to its design). This step is not always taken because of problems of communication between track and OHW staff for planning the track (and OHW) adjustments.

I know that sometimes the OHW is adjusted at the adjacent support locations because the mid-bay stagger seems to be excessive, yet that could be because the track is not in its design position – but the OHW may still be within tolerance and therefore OK.

If the track is outside tolerance, then it's a track problem. If this could be confirmed, then a local agreement could be reached to adjust the OHW as a *temporary measure* until the track gets fixed at a later date, whence the OHW should again be adjusted back to where it was originally designed. But this approach needs to be properly *managed* over time.

As I said, it's not an easy thing to understand how best to deal with this situation, especially considering the practical situation and also the constraint of limited time that normally comes with a closedown.

However, it is an important problem that crops up time and again. So, it's highly desirable that there be a policy (if one doesn't already exist), coupled with suitable training for the various people making these decisions, to bring about the end results of the policy. After all, this can affect the reliability of train running.

Refer to *Section 6.3.2.2*, *Pantograph Security* for a more detailed description.

5.2.6 Testing

5.2.6.1 Electrical

This would typically require testing for *continuity*, *insulation* and *high potential* tests. Refer to the existing Standards regarding the current protocols in place.

A visual inspection is carried out to ensure that all insulators are installed and that there's nothing bridging the live equipment to earth or to track.

CONTINUITY TEST

Passing a medium level current (about 50A or so) through the conductors over an electrical section helps to confirm that there's no discontinuities and high resistance joints.

INSULATION TEST

The bare OHW system insulation integrity is tested – without feeder cables and surge arresters connected (and OHW-to-rail connections removed).

2kV is applied for 1 minute, and the insulation resistance noted. Values of this resistance need to be above a set level to pass this test.

HIGH POTENTIAL TEST

A *Hi-Pot test* (High Potential = high voltage) is carried out on all new OHW.

This test involves removing all HV cables, surge arresters and OHW-to-rail connections, clearing the work site, and then impressing a 6kV high voltage dc source onto the OHW for a few minutes, and checking for a very low leakage current reading on the meter attached to the voltage source.

Performing and passing this stress test helps confirm the longer-term integrity of the OHW system's insulation, before final 1500V power is permanently switched on for powering trains.

5.2.6.2 Pantograph

A test pantograph is run under the unenergized OHW contact wire through all possible train paths (including crossovers and other turnouts), to confirm:

- There are no fittings still in place to strike the pantograph.
- The path under the contact wire is suitably smooth for a pantograph to pass through without being damaged or causing arcing. There are no sudden knocks sounding from this sliding connection and no obvious kinks in the contact wire that the pantograph might react to.
- The path does not cause the pantograph to undergo unexpected large height excursions, (consistent with the tolerable contact ramp rate). This might indicate problems with dropper lengths for instance.
- The take-up of the adjacent contact wire at the various forking-in points is smooth.
- There appear to be suitable passing clearances from the pantograph profile to any surrounding objects (station awnings, nearby OHW fittings, etc.). Note that "Raised & Oscillated" and additional "Electrical" clearances can only be properly checked by a Pantograph Gauge based on measured distances.

5.2.7 Care

As with any line of electrical/mechanical work, it is important that construction and maintenance staff develop a working understanding of the character of the thing being constructed and maintained – in this case, OHW. In most systems, there are things you can get away with and others that you can't.

What's bad is when experienced people do the wrong thing or take improper short cuts, and these actions get noticed and mimicked by relatively new staff, who then tend to think this is

normal practice and so the behaviour gets normalised. This can apply to terminology as well, and although it might seem trivial, a wrong use of a term can have detrimental effects (e.g. using the term "earthing" instead of the term "rail-connecting").

Below are a couple of examples I'm aware of, involving people carrying out work in a manner that can bring about an adverse outcome.

EXAMPLE 1

There was a case where new OHW was being installed over the weekend – all the conductors were tensioned and the final connections were being made – when someone decided to bring the out-of-running twin contact wires into horizontal alignment with each other at a particular overlap location. Unfortunately, the design of the arrangement was such that any significant radial load on the contact wires would cause one contact to be naturally higher than the other (the wires have a spacing of 150mm). The other wire was likely some 50mm or so higher in this case. See *Figure 631*.

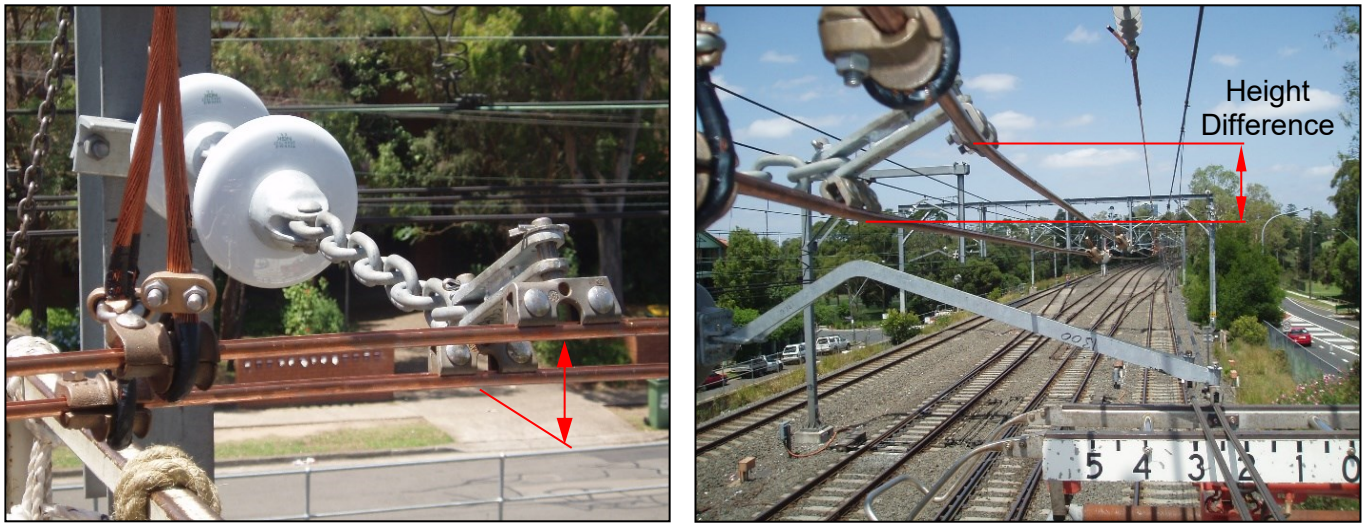


Figure 631 - Type 3G Contact Span providing uneven Contact heights

This situation of one wire being higher than the other was a known outcome of this particular arrangement and was tolerated, even though it gives different contact heights for each wire at the out-of-running location. The OHW is fairly tolerant of this type of error.

However, as I understand it, someone apparently decided to remedy this situation by using a tool to grip onto one of the contact wires (closest to the drop vertical) and rotate it so the other wire would come down to the same level. It might have come down a little, but the radial load would have again caused it to rise. So, they rotated the contact wire again (probably expecting the other contact wire to finally behave). All this achieved was to actually twist the contact wire over a short distance between contact clamp and tool, and in the process, it weakened this wire. Apparently this action was repeated but ultimately the wire was weakened so much that it failed under its high mechanical tension (about 1.2 tonnes).

It was extremely fortunate that no one was injured in this incident. It shows how extreme care needs to be exercised when installing the equipment. If things don't seem to be working as they probably should, then rather than continuing and getting the same result, think about what's really going on. Consult others and think about the "big picture" before continuing to rectify perceived problems.

As is often the case when problems are exposed, some good did come out of the incident, as it prompted some action to rectify the original design. A new arrangement (fitting 354/97) was

developed that would ensure both wires will always be at the same level regardless of the amount of radial load applied (as it is expected to do).

See *Figure 632* for an example of this new fitting in action. Both contact wires are at the same level.

Note however that the pantograph needs to run well below this fitting (typically at least 300mm below), as there's no "heel height" clearance to help clear the pantograph. (But this clearance requirement was also necessary for the old arrangement.)

Figure 632 - New clamp ensures level Contact heights

EXAMPLE 2

Another example is the use of "lindapter" cleats during adjustments. (Refer to *Section 5.1.20.2*, *Cleat Connection*.)

These propriety cleats are sometimes used to clamp an OHW attachment bracket onto a structure flange (typically a universal column used on a mast, portal or drop vertical), per *Figure 633*.

In this case, the cleat clamps onto the inside of the UC flange. This can be particularly useful when cantilevers are installed back-to-back on a drop vertical, which often happens, with the cleats offering the back-to-back brackets total independence without interference from the adjacent cantilever.

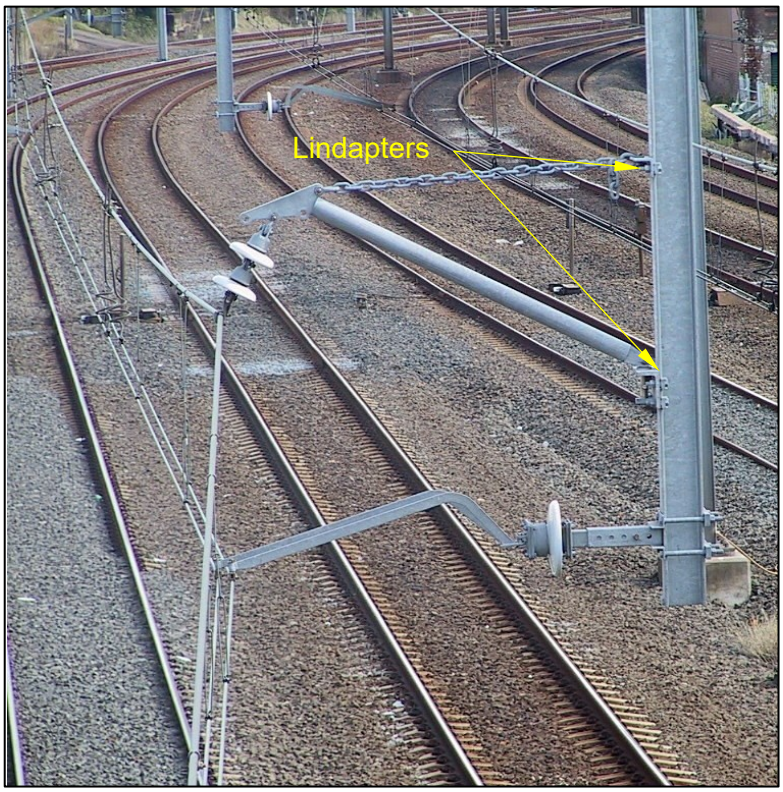


Figure 633 - Lindapters on a Cantilever

On one particular closedown, I remember observing one worker attempting to lower a cantilever jib support bracket down to a lower position on a drop vertical. He loosened the 4 attachment bolts a little but the bracket wouldn't budge, then tried all sorts of things to get the bracket to move, and ultimately resorted to a large sledge hammer and started bashing the bracket down. Although the bracket did eventually come down, this action also succeeded in generating a lot of sweat on his face (and giving him quite a temper in the process), but it stripped the galvanising off the flange as the lindapters and bracket eventually lowered. Of

course, this means the drop vertical will rust in time in these areas, which is a bad outcome. It can also cast doubt as to the long term integrity of the bashed lindapter fitting.

The proper procedure requires the load on the bracket fitting to be properly supported so all the bolts can be loosened, then set *all* the lindapters *parallel* with the flange. Only then should the bracket be lowered in a controlled fashion and retightened. This results in a lot less effort and no permanent damage to the structure and/or lindapters. (In this situation, if a Lindapter rotates it can bind against the flange, and this can be an advantage.)

Lindapters seem to be a good product, and they can be extremely useful in some awkward situations.

Unfortunately, it is actions like the above that can give good device like this a bad reputation among staff, which is not fair.

5.2.8 The Importance of Feedback to Design

If there are problems in the field with constructing or maintaining OHW, sometimes improvements can be made by changing the design. In the past there has been a tendency to fix problems in the field and not involve design staff, and I think this attitude has been, at least in part, to avoid the possibility of getting someone else into trouble.

However, if the Design section is made aware of the issue, then there's a good chance that it can be corrected, and the improvement may then carry into the future at other locations. So communication is essential to improvements.

The examples quoted in the previous section give a hint as to the benefits of communicating back to design the things that don't seem to work. In the first case, a new fitting was developed that prevents the original problem recurring in future.

It's all about good communication. It should be all about trying to *improve things* with a positive attitude (and not be seen as getting someone into trouble), as this can provide significant benefits into the future.

Refer also to *Section 5.1.28*, *Construction of the OHW* for a comment on the importance of building the OHW to the relevant design.

5.3 OPERATIONS

5.3.1 1500V Operating Diagrams

The electrical schematic of the entire 1500V dc electric traction network is covered by a series of "1500V Electrical Operating Diagrams". The configuration and interpretation of these diagrams is shown in *Figure 634*. (Refer to current standards for latest diagram.)

It is of utmost importance that the operators and maintainers of the 1500V network know the status of the installed OHW equipment at any time – this is primarily for safety reasons, and based on operational awareness.

Indeed, I understand there's a legal requirement to keep these diagrams up to date and to maintain a history of all operational changes over time so these changes are traceable – they may be called upon as evidence in a court of law should something go wrong.

This means that before any equipment is livened up and brought into service, operational changes to the infrastructure must be shown on the latest copy of the relevant operating diagram/s for that area of the network.

Importantly, any proposed changes to the network must be shown on a "proposed" operating diagram, which is usually a copy of the existing diagram that's altered to show the proposed changes to be implemented. The drawing will have a new registered drawing number and revisions for traceability and currency. The important thing is that the drawing has to contain the signatures (indicating agreement) of all principal stakeholders, before any changes are planned, designed and finally executed. This process needs to be well controlled due to safety as well as operational concerns.

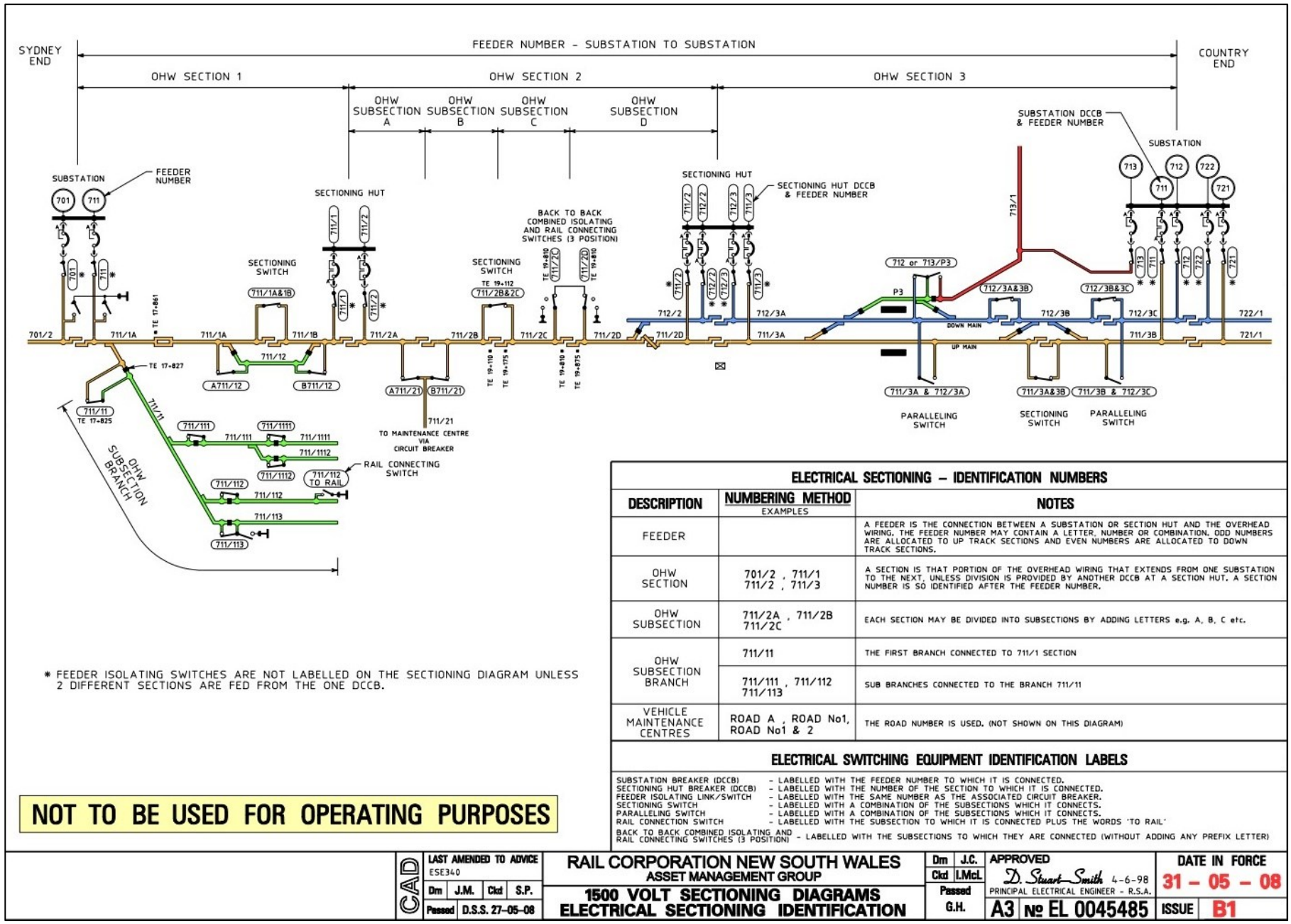
When the changes are finally brought about, the official operating diagram is updated (including its new revision number) to show the new configuration, for subsequent operations.

Big trackwork changes to the network can often incorporate several intermediate stages leading up to the final configuration.

Example: Altered Trackwork for the Chatswood Transport Interchange

> There were 9 different track reconfiguration *stages* (and consequent OHW reconfigurations) needed to bring about the (then new) Epping to Chatswood tracks which came via the new twin tunnels, into Chatswood Station. This work was implemented over a few years leading up to 2007.
>
> This project started off as the original 2 North Shore tracks through Chatswood Station, and ended up with 4 tracks (2 outer North Shore and 2 inner Epping to Chatswood tracks), along with a multitude of crossovers and a new turnback road, all required by Train Operations (apparently needed for maximum operational flexibility).
>
> Both the *Initial* and *Final* stages are shown below in *Figure 635*. (*Note:* RED colour was used to show the proposed new Track Changes for that particular Stage.)
>
> There were 9 different drawings in this set of simple single-line "Staging Diagrams". So, there were necessarily 8 new successive *sets* of signed-off OHW design documentation (Layouts, Profiles, Cross-Sections, Bridge Arrangement drawings, etc.) to accompany the respective track stages. And proposed *1500V Operating Diagrams* accompanied each stage, ready for implementation when trains resumed on the successive new alignment.

Aside: This whole staging process, guided by the Staging Diagrams, worked extremely well here. Interfaces between Track, Civil Works, OHW, Substations, Signals, Communications, etc., were well defined, so that each discipline knew what had to be developed and achieved for the required outcomes at each stage.



ELECTRICAL SECTIONING – IDENTIFICATION NUMBERS

DESCRIPTION	NUMBERING METHOD EXAMPLES	NOTES
FEEDER		A FEEDER IS THE CONNECTION BETWEEN A SUBSTATION OR SECTION HUT AND THE OVERHEAD WIRING. THE FEEDER NUMBER MAY CONTAIN A LETTER, NUMBER OR COMBINATION. ODD NUMBERS ARE ALLOCATED TO UP TRACK SECTIONS AND EVEN NUMBERS ARE ALLOCATED TO DOWN TRACK SECTIONS.
OHW SECTION	701/2 , 711/1 711/2 , 711/3	A SECTION IS THAT PORTION OF THE OVERHEAD WIRING THAT EXTENDS FROM ONE SUBSTATION TO THE NEXT, UNLESS DIVISION IS PROVIDED BY ANOTHER DCCB AT A SECTION HUT. A SECTION NUMBER IS SO IDENTIFIED AFTER THE FEEDER NUMBER.
OHW SUBSECTION	711/2A , 711/2B 711/2C	EACH SECTION MAY BE DIVIDED INTO SUBSECTIONS BY ADDING LETTERS e.g. A, B, C etc.
OHW SUBSECTION BRANCH	711/11	THE FIRST BRANCH CONNECTED TO 711/1 SECTION
	711/111 , 711/112 711/113	SUB BRANCHES CONNECTED TO THE BRANCH 711/11
VEHICLE MAINTENANCE CENTRES	ROAD A , ROAD No1, ROAD No1 & 2	THE ROAD NUMBER IS USED. (NOT SHOWN ON THIS DIAGRAM)

ELECTRICAL SWITCHING EQUIPMENT IDENTIFICATION LABELS

SUBSTATION BREAKER (DCCB)	- LABELLED WITH THE FEEDER NUMBER TO WHICH IT IS CONNECTED.
SECTIONING HUT BREAKER (DCCB)	- LABELLED WITH THE NUMBER OF THE SECTION TO WHICH IT IS CONNECTED.
FEEDER ISOLATING LINK/SWITCH	- LABELLED WITH THE SAME NUMBER AS THE ASSOCIATED CIRCUIT BREAKER.
SECTIONING SWITCH	- LABELLED WITH A COMBINATION OF THE SUBSECTIONS WHICH IT CONNECTS.
PARALLELING SWITCH	- LABELLED WITH A COMBINATION OF THE SUBSECTIONS WHICH IT CONNECTS.
RAIL CONNECTION SWITCH	- LABELLED WITH THE SUBSECTION TO WHICH IT IS CONNECTED PLUS THE WORDS 'TO RAIL'
BACK TO BACK COMBINED ISOLATING AND RAIL CONNECTING SWITCHES (3 POSITION)	- LABELLED WITH THE SUBSECTIONS TO WHICH THEY ARE CONNECTED (WITHOUT ADDING ANY PREFIX LETTER)

CAD | LAST AMENDED TO ADVICE ESE340 | Dm J.M. Ckd S.P. | Passed D.S.S. 27-05-08

RAIL CORPORATION NEW SOUTH WALES
ASSET MANAGEMENT GROUP
1500 VOLT SECTIONING DIAGRAMS
ELECTRICAL SECTIONING IDENTIFICATION

Dm J.C. | Ckd I.McL | Passed G.H.

APPROVED D. Stuart Smith 4-6-98
PRINCIPAL ELECTRICAL ENGINEER - R.S.A.

DATE IN FORCE 31 – 05 – 08

A3 № EL 0045485 ISSUE B1

Figure 634 - 1500V Electrical Sectioning Identification diagram

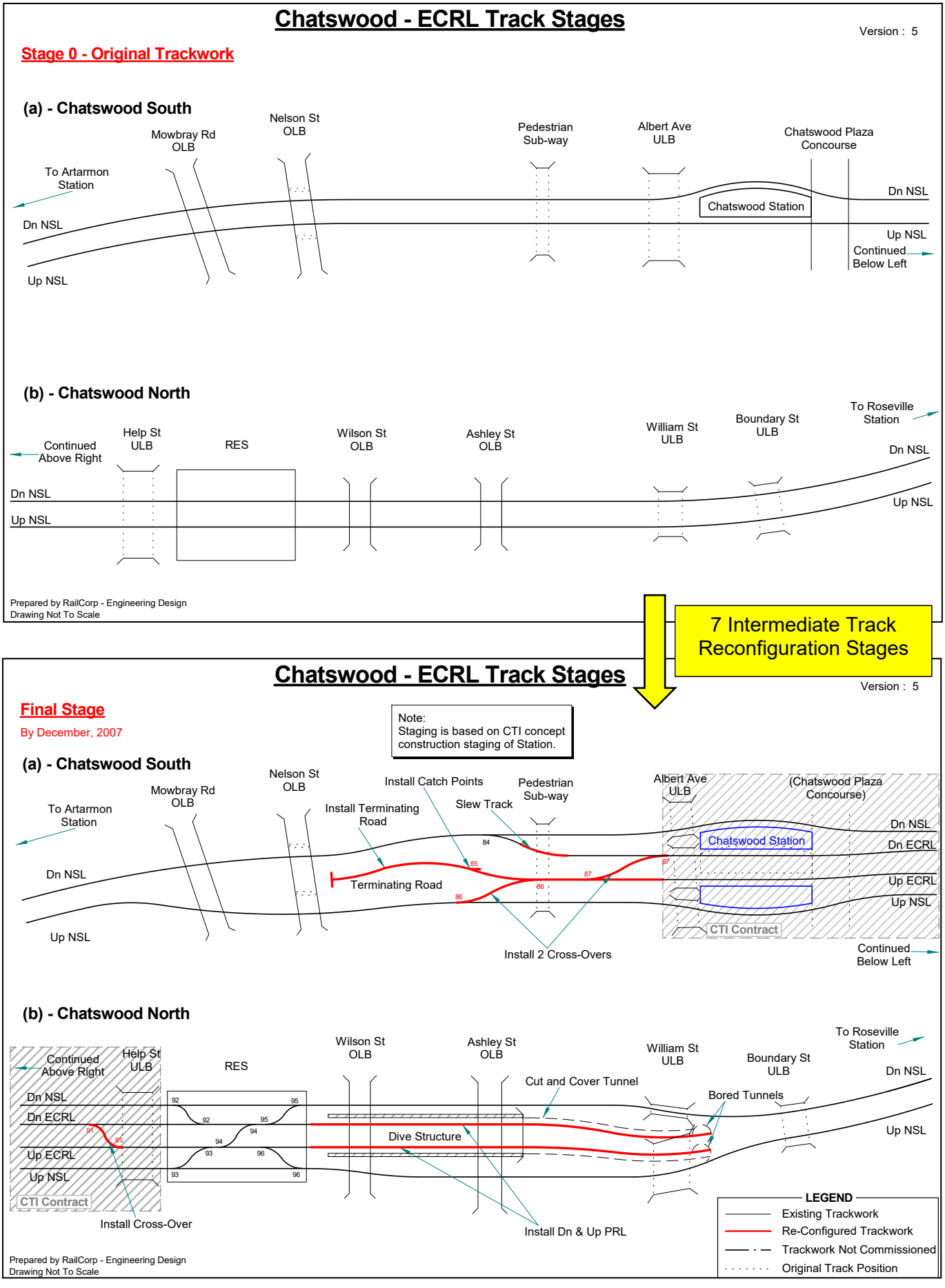


Figure 635 - Chatswood Track Reconfiguration Stages – Initial tracks (top) leading to Final tracks (bottom) in 9 stages

5.3.2 Electrical Section Numbers

The entire OHW system is divided into a whole lot of unique *Electrical Sections*. This enables various parts of the system to be conveniently energized, or conversely to be isolated from supply (and rail-connected before work can be carried out on the OHW).

In addition, should an electrical fault occur on the OHW system, causing the electrical protection to operate, the extent of the resulting 1500V isolation can be limited to one or only a bare few electrical sections, which aims to prevent disruptions to trains running nearby.

The structure of the electrical sectioning scheme is depicted in *Figure 634*.

Electrical Section Numbers were introduced as a way of *uniquely* identifying each Electrical Section. This is important as it has safety-critical implications. (E.g. workers need to know the relevant Electrical Section to isolate and rail-connect before being worked on.)

The *naming* of each Electrical Section must follow the guidelines set up a long time ago. This includes providing subsection numbers where necessary.

The *labelling* of all relevant OHW equipment with the corresponding Electrical Section Number/s is also important, and this labelling must be the same as that shown on the current operating diagram/s. The labelling is included at locations such as Substations and Sectioning Huts, and at the multitude of local switch locations.

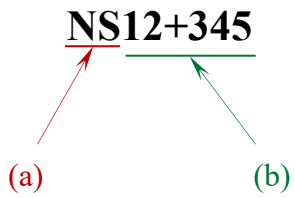
It is crucial that *all such labelling be kept up to date* when changes occur to the system.

5.3.3 OHW Location Numbers

The OHW infrastructure is fundamentally a linear entity, so in order to locate specific OHW assets unambiguously, they are given a unique *OHW location number*. This is based on its ***approximate*** kilometrage from Sydney.

This label must appear on all OHW structures and other locations such as overline bridges where the OHW is attached, i.e. where it's supported and/or registered, or anchored.

The location number has the following format:



(a) ***Location Prefix*** – a 1, 2 or sometimes 3 character *prefix* that is used to define an electrified area, and to allow OHW assets to be *uniquely* identified in the field (if they have the same kilometrage as assets located elsewhere). See *Table 49* below for the list of prefixes and their respective locations (as at 2014 I think). Refer to the Standards for the most up-to-date list.

(b) *Approximate **kilometrage** from Sydney's Central Station*, with a "+" sign replacing the decimal point, to indicate that it's an "Electrical kilometrage" (not to be confused with the track kilometrage). The above example would be very roughly 12.345km from Central (i.e. resolution down to the metre, but it's an approximate number only and may vary from the track kilometrage by many metres at that point).

Main Lines

Prefix	Location	Meaning When First Used
AL	Prince Alfred S/S to Wolli Creek (NSR)	Airport Link
B	Meeks Rd S/S to Sefton S/S (Bankstown Line)	Bankstown
CC	Clyde to Carlingford	Clyde – Carlingford
CE	Central – Goulburn St	Central
CI	City Inner, Goulburn St / Goulburn St	City Inner
CK	Coniston – Kiama	Coniston – Kiama
CO	City Outer, Goulburn St / Goulburn St	City Outer
DES	Central to Bondi Jn (ESR)	Down Eastern Suburbs
DIR	Erskineville to Central (ESR)	Down Illawarra Relief
DS	Central to Argyle S/S	Down Shore
EH	East Hills to Glenfield Jn	East Hills
G	Granville to Cabramatta (excl)	Granville
GB	South West Rail Link	Glenfield to Bringelly
H	Strathfield – Hornsby	Hornsby
HB	Homebush Bay Loop	Homebush Bay
MH	Milsons Point Sidings to Hornsby (excl)	Milsons Point – Hornsby
ML	Macquarie Line (Epping Chatswood)	Macquarie Line
MS	Macdonaldtown – Granville S/S	Main Suburban
N	Hornsby Station – Newcastle	Newcastle
NS	Argyle S/S to Waverton (excl)	North Shore
R	Blacktown to Richmond	Richmond
S	Lidcombe to Macarthur	South
SC	Sutherland to Cronulla	Sutherland – Cronulla
SL	Granville S/S to Bowenfels	Sydney – Lithgow
SW	Central – Coniston	Sydney – Waterfall
TE	Turrella to East Hills	Turrella – East Hills
UES	Central to Bondi Jn (ESR)	Up Eastern Suburbs
UIR	Erskineville to Central (ESR)	Up Illawarra Relief
US	Central to Argyle S/S	Up Shore
WP	Coniston – Port Kembla	Wollongong – Port Kembla

Goods Lines, Sidings and Yards

Prefix	Location	Meaning When First Used
B	Sydney Yard	Bankstown
BL	Campsie to West Junction (Flemington)	Belmore -Lidcombe
BW	Marrickville to Tempe	
D	Wardell Rd Jn to Catherine St OLB	Dulwich Hill
E	Eveleigh Yard	Eveleigh
E	Enfield Yard	Enfield
F	Flemington Maintenance Centre	Flemington Yard
FL	Flemington Middle Junction to Lidcombe Shuttle	Flemington – Lidcombe
GL	Sydenham to West Junction (Meeks Rd)	
GL	Glenlee Coal Siding	Glenlee
HL	North Strathfield to Homebush	Homebush Loop
HW	Homebush Bay West Fork	Homebush Bay West Fork
IH	Inner Harbour Balloon Loop (Port Kembla)	Inner Harbour
L	Delec Sidings	
LL	Lidcombe Loop	Lidcombe Loop
LW	Former Loco Works (Chullora West Junction)	Loco Works
M	Mortdale Maintenance Centre	Mortdale

MC	Macdonaldtown Turnback	Macdonaldtown
PK	Port Kembla Balloon Loop	Port Kembla
RC	Siding on former Ropes Creek Line	Ropes Creek
RY	Rozelle Yard	Rozelle Yard
SD	Rosehill to Sandown	Sandown

Table 49 - OHW Location Number Prefixes

Note that there are some instances of conflict in *Table 49* where prefixes had been duplicated (I'm not sure what happened there).

As hinted in (b) above, there seems to be much confusion over OHW location numbers that appear on OHW structures. The OHW "kilometrage" should not be confused with "track kilometrage" – they are totally different distances, for 2 reasons:

- They start at different locations at Central – see *Figure 636* below, and
- Track km is determined on the linear geometry, normally measured *along* the down rail of the down track (and adjusted where necessary), whereas the OHW km is based on *straight-line chords* from one OHW support location to the next, which emulates the straight line of a strung catenary wire (in plan view). This naturally gives reasonable distance errors compared with the track km, especially around tight track curves.

For electrical work, this kilometrage error is not that important – the fundamental purpose for the OHW location number is to act as a *unique name* (for reference). It's a "pointer" to a unique OHW asset, so maintenance staff in particular can be guided to a particular location in the system without any ambiguity. This *uniqueness* has significant safety implications.

The prefix is necessary as tracks radiate out in all directions from Central Station (zero km reference), and applying a prefix allows several structures to have the same km number yet still remain unique, e.g. N123+456 and SW123+456 are totally different locations even though they have the same "OHW" kilometrage.

Older OHW Location Numbers were in the imperial units of feet, with *2 digits* after the "+" sign (separating hundreds of feet from tens of feet), e.g. "MS123+45". For conversion to metres, multiply the entire number by 0.3048, so this example would be equivalent to MS3+762 in the current metric scheme.

Note also that the policy was for the last digit to be simply truncated – 3,762.8 (m) becomes 3,762 (again indicating that distance accuracy is not that important).

Sometimes people subtract OHW location numbers to get distances (e.g. the bay length between masts), and obviously from the above paragraph, this is more than likely to result in some degree of error. Even if the structures were labelled with track kilometres, there is no guarantee of an accurate distance result, because there may be a *track kilometrage adjustment* involved in between these structures, and this can lead to a totally erroneous distance. (Also, the distance is along the rail instead of a straight-line chord.)

Instead, a (fibreglass) tape measure is the way to go if you need any degree of accuracy and confidence in the situation.

Or better still, use an accurate CAD layout plan showing as-built mast positions and projecting out to the centre of track as the reference points. Alternatively, for a reasonably accurate distance, rely on as-built survey results from mast locations (e.g. subtracting the eastings and northings of each location – see *Section 5.1.31*).

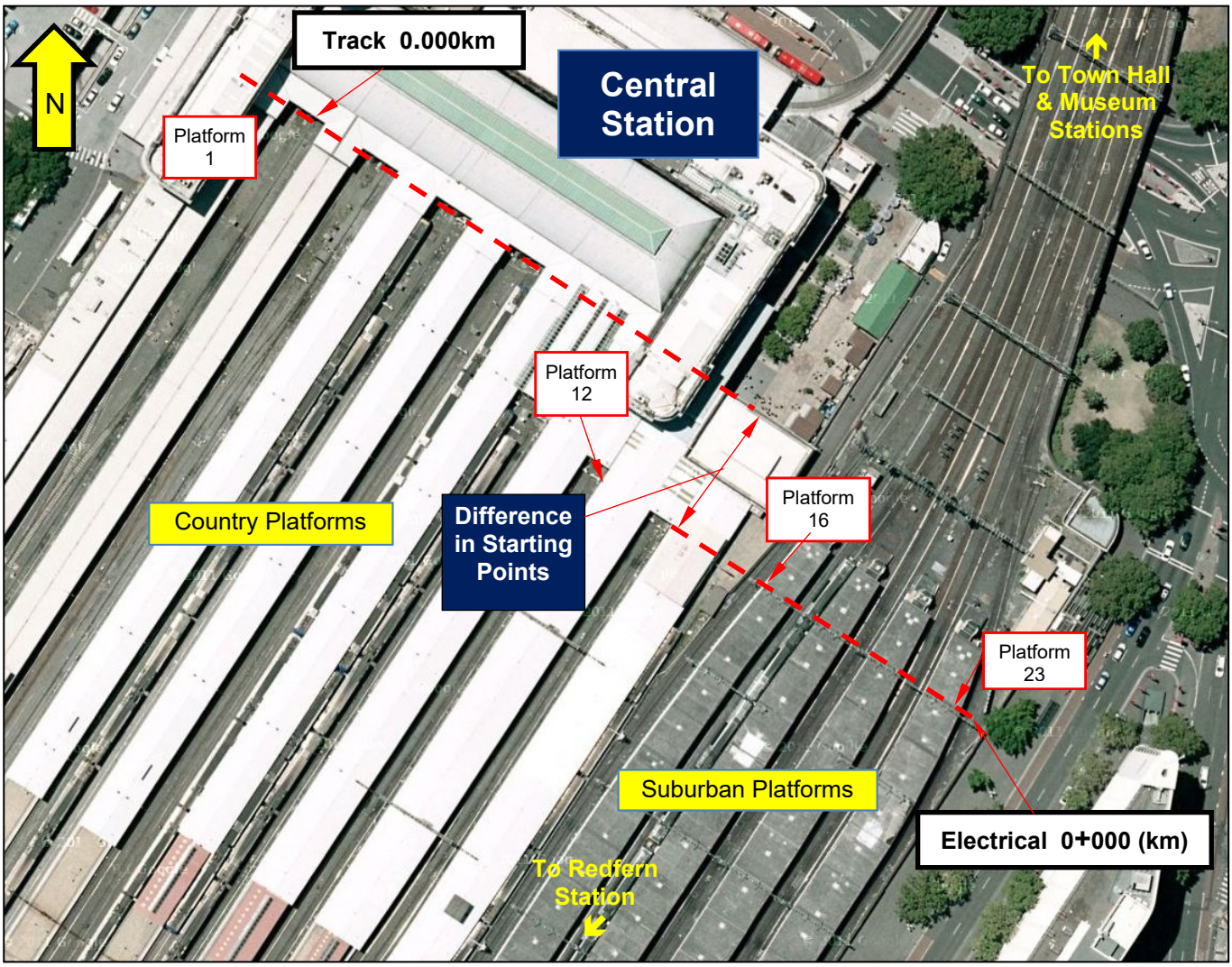


Figure 636 - Relative location of Track 0.000km versus Electrical 0+000km

Aside:

Steel measuring tapes are not permitted in the rail corridor, apparently because of the fear that they might easily short-circuit the 2 rails of a track and confuse the signalling system(?). There are other electrical reasons too! It's all too easy for a steel tape to be extended, then buckle and fall onto things it was never intended to come near!

Almost 30 years ago I was involved in the investigation of an accident at Punchbowl Maintenance Centre, where a contractor fell from a height. As I recall, even though a large timber barrier was installed to warn people to keep away from the live 1500V OHW, he gained access to a catwalk beyond the barrier and used a steel tape to measure along a large diameter pipe which was located diagonally above the OHW. Apparently, as he was retrieving the well-extended tape, it suddenly buckled and swung down onto the nearby OHW. He fell (about 6m), more likely as a result of the bright flash and loud noise (apparently there were no burn marks to body). Remnants of the tape were in small charred pieced. He survived the fall.

A Recurring Problem

For Electrical, Civil and Track design work, the Computer Aided Design package called "MicroStation" was adopted by Sydney's Railway from the early 1990s. It's an extremely powerful package which forms the basis of almost all drafting work and increasingly more pure design work, by the above design groups.

However, when doing *track design* work on "Horizontal" and "Vertical" alignment drawings, this program automatically uses the "+" sign instead of a "," symbol when denoting "thousands" of metres. So, for example, a track kilometrage of 1,234.000m (down to the millimetre) automatically displays on these drawings as 1+234.000 (and truncated to 1+234).

This is extremely unfortunate, as it goes against the fundamental understanding from the first days of Sydney's electrification, that the number with a "+" sign be *reserved as an Electrical location number*, and importantly should be treated as an *approximate kilometrage only for uniquely referencing specific OHW assets*.

This conflicting situation poses a risk of someone misunderstanding what the information really represents, and using it inappropriately. There were steps taken around 2005 to stop this CAD problem from continuing, but the consequent work-around seemed to prove unsuccessful, and therefore the risk probably remains! What to do?

This issue was raised as an area for improvement in *Section 5.1.33*, *OHW Location Number Conflict*.

5.3.4 Electrical Operating Centre

The operation of Sydney's entire electrical traction network used to be controlled by the Electrical Operating Centre (EOC), which had its main centre at Prince Alfred Substation (top level) located adjacent to Central Station. The entire operations could also be controlled at one stage by the satellite Operating Centre located near Newcastle (for redundancy), but this no longer exists.

At some time just before 2014, the EOC had moved, to be centrally located along with 5 other rail operations groups (and help desks), into what is apparently now called the Infrastructure Control Centre (ICON) and located at Sydney Central Station. It operates 24/7. Unfortunately, I don't know anything about this new facility, but I expect the main functionality remains. The big benefit of the new structure is the direct & immediate access to other co-located control centres, which is especially important during incidents involving many disciplines on the rail network.

The electrical network under control mostly includes the high voltage ac network (132kV, 66kV, 33kV, 11kV and 2kV), as well as the 1500V dc network that directly supplies trains with power.

This centre used to be known colloquially as "Electrical Trouble Office" or simply "Elec Trouble" or even "Trouble" (which is a bit unfortunate).

It was responsible for the coordination of the electrical network, and interfaced directly with the Signal Trouble Office counterpart and Train Operations (as said, now all co-located).

It had direct control over the multitude of substations and sectioning huts through the SCADA network (abbreviation for *Supervisory Control and Data Acquisition*). It controlled supply through the network of ac circuit breakers and dc circuit breakers (DCCBs), and could monitor the *status* (open / closed) of most of these items and various other conditions throughout the network.

It also helped control the electrical supply to areas like railway stations, workshops, and associated buildings, and services (including lifts and escalators), signal supply, etc.

When someone required the power to be removed to the Overhead Wiring, it was coordinated through the Electrical Operating Centre. (The DCCBs are operated remotely by the EOC, or locally by substation staff, but their operation has to be done in conjunction with EOC.)

5.3.5 Electrical Irregularities

The Electrical Operating Centre used to routinely publish a list of "Electrical Irregularities", which were events that impacted the electrical network in some manner (big or small), and that need recording and possible follow-up action.

These events could be communicated to EOC by the maintainers, train drivers, police, the general public, etc.

Some samples of OHW-related irregularities from various dates are shown in *Table 50*. This includes events such as:

- Tension regulator weights bottoming out.
- Pantograph damage; some wind storm impacting the network at the time.
- Drama when a person stood on a "smoke screen" (horizontal safety screen on bridge) above live OHW, which involved police and stopped trains for almost 1 hour.
- Truck hitting boom gate which tangled in the OHW.
- Inspection of OHW after a report of the catenary being struck by some vehicle.

Some of the entries in the irregularity report need a bit of interpreting (sometimes due to stress and urgency to get things fixed), but there's usually enough information to get the general idea, and the staff who made the entries could be contacted for more details later on if needed.

This system seemed to work well, and it provided a great way of communicating all sorts of things to all sorts of people involved in the operating railway environment. Indeed, the information (and especially time stamps) could be called upon as evidence to be used in subsequent investigations, reports, courts of law, justifications for system improvements, etc.

Ref.	Location	Date/Time	Resp.	Description	Area	Effect	Details
79360	Meadowbank	17/12/2009 13:20	Infra - Electrical	Tensioning Weights sitting on ground OHW	District North	Minor / No impact	OHW tensioning weights sitting on ground at 18+653km & 18+694km on Down Main. 40km speed restriction required on the Down Main between Meadowbank Bridge and West Ryde Station. Temporarily raised weights, overhead wire OK for normal running.
82062	Marrickville NSW	4/04/2010 6:19	Infra - Electrical	Run 705A panto. damaged	District Central	Minor / No impact	Run 705A has damaged leading pantograph and is standing on the up platform at Marrickville. Patrols on the Up track Campbelltown to Marrickville. Emergency outage on the Up Bankstown 1500V section 201/1B to lower pantograph. Pantograph started arcing as run left Campbelltown. Campsie to Marrickville, run at caution Campsie to Sefton. Patrolled overhead wire Liverpool to Sefton OK. Campsie to Marrickville OK, Campbelltown to Glenfield found broken wearing strip at S54+381.
100509	Mt Victoria NSW	25/05/2012 23:19	Infra - Electrical	Report of Tree branches in 1500v O/H	District West	Minor/ No Impact	Bark in 1500v O/H at SL 125+500 Mt Vic but had blown away. Tree branches brushing up against train. Tree branches removed and supply restored.
100511	Dapto NSW	26/05/2012 2:42	Infra - Electrical	Object caught in Overhead Dapto loop line	District Illawarra	Minor/ No Impact	Object caught in the overhead Sydney side of the loop line Dapto. plastic wrapped around a dropper and is above contact so won't affect train travel. Plastic wrap removed from around dropper.
100528	Strathfield	26/05/2012 12:15	Infra - Electrical	Report of Gutter Hanging from Platform	Infrastr. Facilities	Minor/ No Impact	Piece guttering hanging from the station building on platform 7. Will require a 1500V Authority on 1500V Section 335/1c the Up Local in order to remove guttering. Guttering removed All supplies restored.
116679	Ingleburn NSW	19/04/2014 19:46	Infra - Electrical	Person on Smokescreen	District Central	No Impact	Report of person on Smokescreen at Ingleburn Station 1500 volt supply removed from OHW Glenfield to Minto. IMF2 declared. Police have removed self harmer and ok to restore supply to OHW. 2035 hrs supply restored to 1500 volt OHW Glenfield to Minto.
116527	Granville NSW	13/04/2014 8:56	Infra - Electrical	Truck hit boom-gate	District West	No Impact	Report of truck hitting Boom-gate at Parramatta Road level crossing and that Boom-gate is stuck in OHW Boom-gate sitting in OHW and appears to be made Aluminium. Removed 1500 volt supply to Carlingford line, 741/1 and 741/2 sections. Boom-gate removed from OHW and ok to restore supply on Auth E20/14. 1019 hrs EOC advised Outer Traffic supply restored on Auth E20/14
116813	Redfern NSW	26/04/2014 14:22	Infra - Electrical	OHW Catenary Wire Struck by Vehicle	District Central	No Impact	Report of machine impacting overhead wire on the Up Illawarra at 0+707 and on the Down Illawarra Local at 0+800. Inspected overhead wire at 2 locations no visual signs of damage

Table 50 - Various samples of Electrical Irregularity Report (OHW entries only)

5.4 MAINTENANCE

Although the "maintenance" of OHW covers many aspects, in this document I can only cover a few areas, and in not much detail. So, for what it's worth …

5.4.1 Districts

The maintenance of OHW was / is covered by the various "Districts" set up for that purpose.

In the early years, I understand the main focus for maintenance management was carried out at Leichhardt Depot, with other depots at Hornsby, Sefton, etc. In those days the Railways was also responsible for the large network of Trams in operation in Sydney, until they ceased operations in about 1961.

The districts have changed many times over the decades, I guess (at least partly) in response to the vast extension of the electrified network – particularly in the south to Kiama, in the south-west to Campbelltown and Leppington, in the west to Lithgow, in the north-west to Richmond, in the north to Newcastle.

But the fundamental districts in the 1980s seemed the most logical areas, and they will be described here (since things seem to continue to change) – 4 Regions, and with each Region having 2 Districts (a total of 8 Districts):

- North Region – Hornsby District and Newcastle District offices
- Central Region – City Underground and Sefton District offices
- West & South Region – Clyde District and Valley Heights (Lawson) District offices
- Illawarra Region – Hurstville District and Wollongong District offices

In 2012 the altered composition was as shown in *Figure 637*, although this has no doubt also changed by now, including the location of the various depots.

5.4.2 RVX-4

Many decades ago now, a special track-mounted vehicle known as "RVX-4", was fitted out with dedicated sensors to record the position of track and various aspects of the OHW on the fly.

It would routinely run around the electrified network with the aim to try to pick up any "exceedances" in the OHW system throughout each bay. The parameters included the *contact height* (too low or too high) and *contact stagger* (greater than a certain amount), but it also picked up the track superelevation, and maybe a few other things relevant to the OHW system (such as temperature for any fixed-anchored OHW assessment, as I recall).

The exceedances would be manually interpreted, and the District could then be involved to investigate further if needed, feeding into their work schedule. This work sometimes involved the OHW design section, for their assessment and possible resolution if needed.

It is likely that this vehicle has been replaced by more up-to-date methods now.

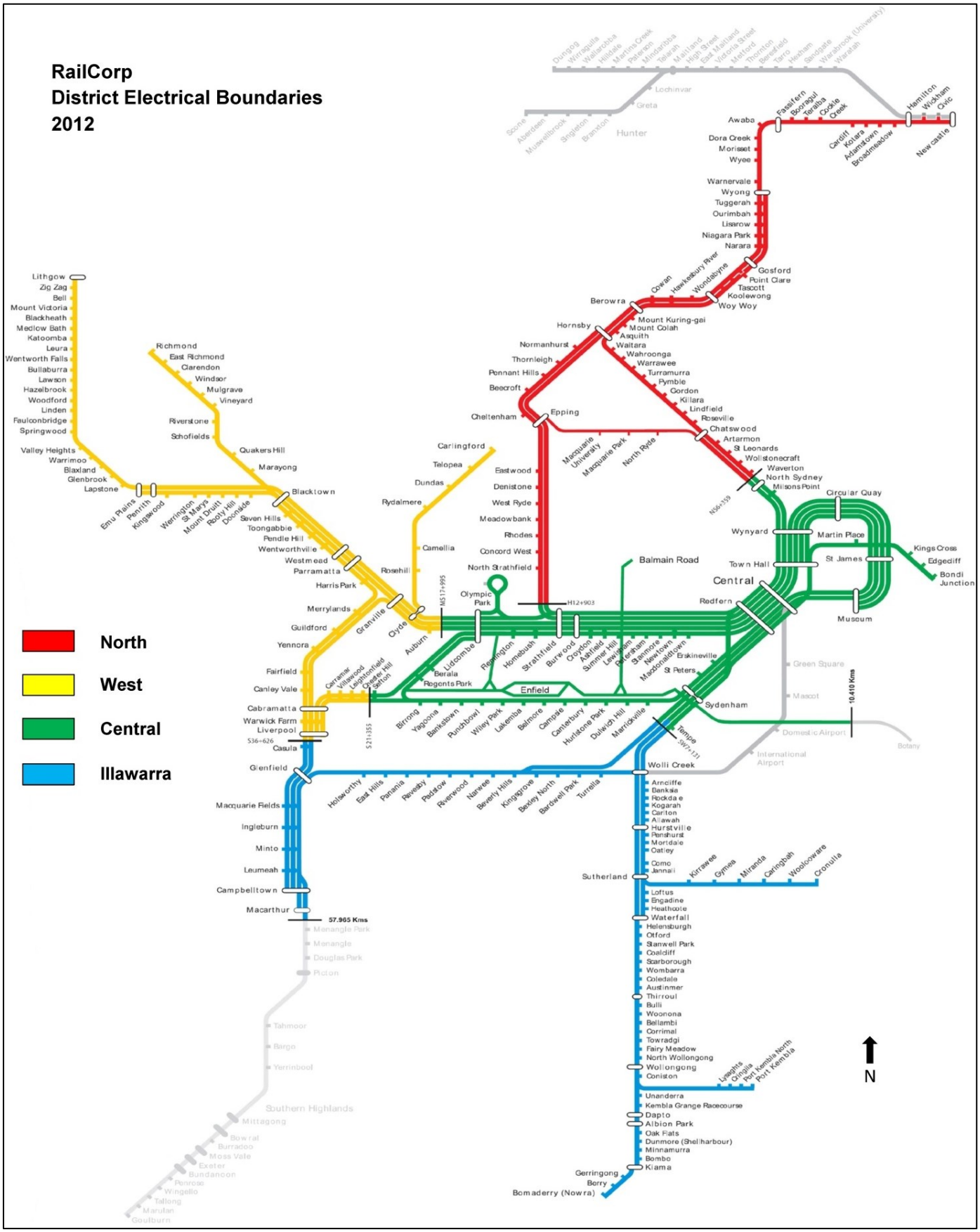


Figure 637 - Sydney's 4 OHW Maintenance Districts as they were in 2012

5.4.3 Isolations for OHW Repairs

To affect repairs, the OHW must first be made safe to work on, i.e. the 1500V supply must be *de-energized*. In a longitudinal sense, it means removing supply for the entire electrical section (and depending on the electrical configuration, sometimes even removing supply from the next and/or previous sections). In a lateral sense, this can also mean removing supply from the OHW servicing any track/s immediately adjacent to it.

To safely work on the OHW also requires the OHW conductors for that electrical section to be "rail-connected", meaning that the OHW conductors are electrically bonded to track. This makes the OHW the same electrical potential as the track that their vehicles would be running on. (Note that in this situation the OHW is NOT earthed – it must be directly connected to track, with a heavy-duty copper cable – "rail-connected".)

The *OHW-to-rail connections* can be made:

- At *substations* or *sectioning huts* with appropriate switches intended for such action,
- At permanent *track-side switches* with rail-connecting switch positions or facilities, and
- *On track* using "portable rail-connecting equipment".

Specification A-842 used to describe the standard *portable rail-connecting equipment*. *Figure 638* shows part of a drawing (I think from the 1990s) of the kit called up in this Spec.

It consists of a length of heavy-duty, but very flexible, *copper cable* of about 120mm² copper with numerous fine copper strands (Item 3), with a sizeable *rail clamp* at one end (Item 2) and a *contact clamp* (with detachable bayonet connection) at the other end (Item 1).

The heavy duty rail clamp is connected to the bottom flange of the rail. This clamp has hardened serrated teeth that, when screwed down onto the flange, bite through any surface rust on the rail and into solid steel, resulting in a very low resistance connection.

A special *insulated stick* (Item 6) is used by a lineworker to install the contact clamp when standing on the track below. The insulated stick enables the contact clamp to be raised over the contact wire and then rest on it. The clamp is then tightened by screw action onto the contact wire by rotating the stick. The clamp makes a good electrical connection to the underside of the contact wire, which is usually flat and shiny from recent pantograph wear, which helps to ensure a good electrical connection is made.

When the contact clamp has been installed, the stick can be removed by pushing it up and rotating it to release its bayonet connection to the clamp. This then allows the

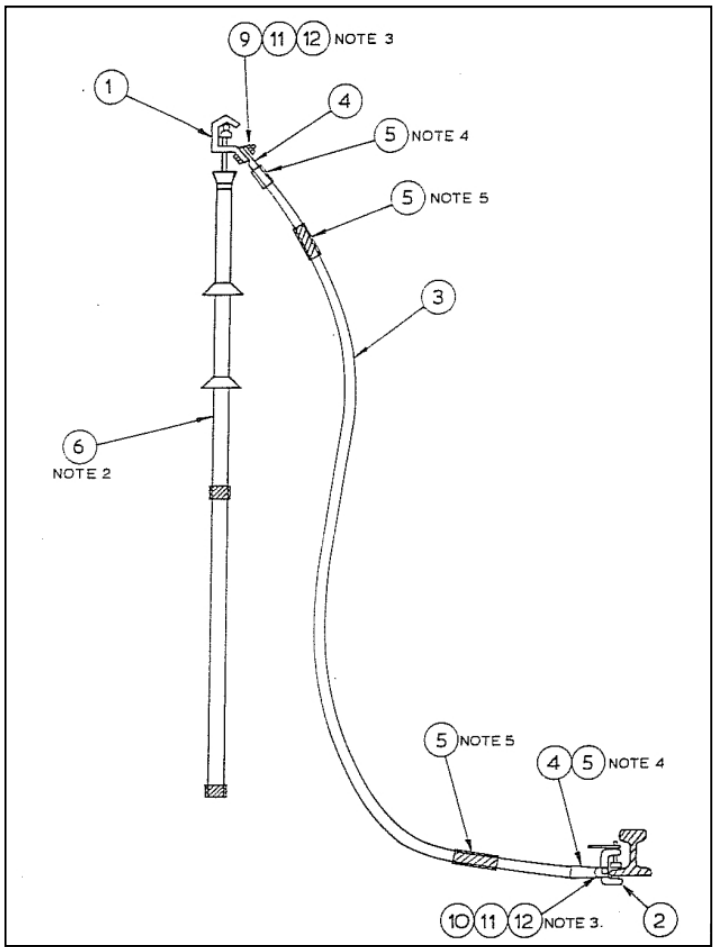


Figure 638 - Typical Portable Rail-Connecting Equipment

remaining rail-connecting cable to be swung out of the path of any passing rail-mounted vehicles or diesel/steam trains.

The rail connections are normally applied at both extreme ends of the electrical section (which could be kilometres apart), with additional rail connections applied in the immediate vicinity of the work area to further ensure that the OHW cannot be energized.

However, if the situation is classified as an emergency, and special "rail connections" cannot be immediately applied, then there are (or have been) other instructions that can be followed, mostly so as to get people out of trains and make the situation safer, e.g. for emergency services.

Because this is a safety related aspect, the reader should refer to Sydney's Electrical Safety section for the most up-to-date information on dealing with electrical isolations.

5.4.4 Special Events

At times, there have been significant events occurring in Sydney, and in the lead up to these events considerably more effort has been put in place to closely scrutinise the condition (including alignment) of the OHW assets in order to prevent a major OHW failure during the event. The flow-on effects of damaged OHW to the rest of the train network are often huge.

A good example was the 2000 Sydney Olympics, commencing 15 September, and following Paralympics commencing 18 October. This once-in-a-lifetime event (for Sydney) demanded uninterrupted train services throughout the electrified network over a period of several weeks during the sporting events. Of particular importance was the (then newly constructed) track loop configuration into Olympic Park (for the Olympic Village) –focal point of the events.

The most vulnerable areas for potential OHW damage were (and are) the numerous junctions located throughout the network. For the above event, it was especially important to closely inspect the area near Strathfield and Homebush, because vast numbers of trains came from the north, south, east and west to converge into Strathfield Station, which is adjacent to the Homebush – Olympic Park – Lidcombe area. And there are an enormous number of crossovers in and around this heavily used region.

5.4.5 The Importance of Feedback to Design

As mentioned in *Section 5.2.8* (for construction), it's most important that any problems with maintaining the OHW be fed back to design or standards, so that any issues can be thought through and dealt with if necessary – for reasons of continual improvement into the future.

5.4.6 The Technical Maintenance Plan for OHW

In the mid-1990s a massive assessment effort was undertaken by most Engineering sections of the "NSW Railways", to bring about a "Reliability Centred Maintenance" (RCM) approach to railway infrastructure maintenance. The work ultimately led to an associated "Technical Maintenance Plan" for each Engineering section. This included the "Electrical Power" discipline as described in *Section 1.7*, with subsections listed in *Table 2*. Overhead Wiring was given the subsection number of 8, and identified as "*EP-08*".

A "FMECA" process (acronym for Failure Modes, Effect & Criticality Analysis) was employed to *identify* all equipment and components, then analyse how it *failed* and what *impact* that had on the system, etc. See *Section 5.6.3* for more details on this process.

For the OHW, this meant identifying and analysing all the common OHW systems, but it also required going out to all Districts to find out any "unique" OHW systems that still exist, for a more complete picture of what made up Sydney's OHW system.

This FMECA work led to the development of Service Schedules. These list the various tasks to perform at appropriate intervals, with the aim to more effectively maintain the equipment. This was supported by publications on how the various maintenance activities called up were to be performed, as endorsed by the relevant Standards group. For the OHW (and for HV Aerial Lines), the Service Schedule activities were generally categorized as:

- ***Patrol*** – On a more frequent basis, workers would walk beside the track and look for specific problems – tasks as listed in the Service Schedule, often using binoculars (to try to get more close-up detail from ground). The tasks are essentially surveillance activities.
- ***Hands-On*** – This required power outage so that workers could actually put their hands on the equipment in an elevated vehicle. This was most effectively performed in wire runs, and based on Electrical Sections (that could be taken out of service).
- ***Post Event*** – Events including Bush Fires, Floods, possibly Strong Winds(?), etc. had their own dedicated Service Schedules listing tasks to be carried out post (after) the event.

The periodicity of carrying out each Service Schedule was also established. The period could be adjusted to suit the specific equipment and its environment (within certain time bands), e.g.

- Patrols carried out every 6 weeks (+2 weeks, -1 week),
- Hands-On every 4 years for fixed-anchored OHW (+2 years, -2 years).

The provision of spares and consumables for equipment maintenance could also be better established and managed with this process.

There were to be other important outcomes of the RCM process (not discussed here).

5.4.6.1 Patrols

In the old days, regular patrols were carried out by walking near the track and trying to see any signs of problems with OHW equipment in the various runs of OHW. I think the intent was to carry these patrols out every 6 weeks or so (?), but there's a huge amount of OHW out there for the various Districts to look at in that time.

I understand that special short focal-length binoculars were used to help gain a closer view of the wiring whilst keeping clear of the running lines.

Any identified issues were recorded. It seems that the issues could generally be dealt with in a few ways:

- If the problem was fairly trivial and deemed not likely to cause an immediate problem, keep an eye on the situation in subsequent patrols, but also list if for correcting later on when hands-on work was to be carried out with power off.
- If the problems was more serious but could still last a while, then make arrangements to plan for power off to correct it. The timing depended on the severity of the problem and judgement of how long it would likely last before causing major problems.
- For serious problems that are likely to cause more immediate damage or safety issues, they it may be appropriate to "Stop Trains", take power out and correct the situation before it has a chance to fail.

The newer Technical Maintenance Plan changed the approach, from looking at absolutely everything during a Patrol (which was asking a lot), to mainly focusing on just the items nominated in the relevant Service Schedule (although any obvious signs of other problems should be noted and dealt with also). Events such as "Post (after) Bush Fire" and "Post Flood" had their own Service Schedules listing the activities to perform.

5.4.6.2 Hands-On

Because the OHW is very much a mechanical system (that delivers electric power) which comes into frictional contact with pantographs, and is located mostly in the outside environment and subject to the elements and other adverse impacts, it needs to be periodically examined *close up*, ideally with hands checking around for likely problems. The more frequent patrols, viewed from a distance, can only achieve so much.

So, every 4 years (for fixed-anchored OHW) or 8 years (for regulated OHW) the power is turned off and most equipment gets a close examination for problems like:

- corrosion,
- rattling / loose fittings,
- worn parts,
- evidence of burn marks or annealing of conductors,
- mechanical damage including impact damage,
- evidence of current leakage across insulator surfaces,
- flashover marks caused by lightning,
- arcing damage possibly caused by pantographs, or by outside interference such as conductive objects falling onto the OHW,
- etc.

As with the "Patrols", the "Hands-On" *Service Schedules* dictate what specific action needs to take place, based on the specific identified failure modes of the various equipment and components (the FMECA process).

5.5 FAILURE MODES

All manner of OHW equipment has been installed in Sydney since 1926, and over the intervening period successive OHW engineers have developed an understanding of what works and what doesn't work with regard the OHW itself, in this at times harsh environment.

Today, thanks mostly to the amount of OHW that's been renewed and more importantly regulated over the past few decades, if the OHW has been properly designed and constructed, it remains extremely reliable.

Probably the biggest single design concern is the catenary and contact wire behaviour when the conductor temperature changes. So, *regulating* the OHW is a major improvement – allowing the wires to move longitudinally instead of up and down in each bay (per *Figure 24* near the start of this document). This way of dealing with changes in wire length is most important when the OHW is located out in the open and subjected to wide temperature extremes (and we seem to be seeing many more extremely hot days now!).

I think the items in the following subsections are some of the main contributors to *reduced* operational reliability, based on the following 3 aspects: ***outside influence***, the ***OHW condition itself*** and ***interface issues***.

Just to give some idea of the variety of typical failures, *Table 50* (further back) lists some sample events affecting OHW that have occurred at various times.

5.5.1 OHW Failures Due to Outside Influence

The outside world can be extremely harsh at times – with temperature extremes, bush fires, lightning, strong winds, snow build-up, etc. The OHW needs to be properly designed and be robust enough to confront these elements and survive (to a high degree).

5.5.1.1 Wind

High wind speeds can lead to a huge amount of contact wire blowout and loss of pantograph security, if speed is greater than the OHW is designed for, or if the OHW is not maintained properly (e.g. having conductor tensions lower than they're meant to have).

Wind can also overstress other OHW equipment, especially if the equipment is in poor condition (e.g. rusted). This importantly includes the numerous OHW support structures. They wild nature of wind gusts can be particularly nasty in this regard.

Wind can also pick up and blow other objects onto the OHW, including roofing materials, corrugated iron, barbecue covers, plastic bags, trees (see below), etc. Some situations with these objects can require immediate attention, i.e. stop trains to fix.

5.5.1.2 Trees Falling on OHW

Tall trees often line the rail corridor throughout the rail network.

Strong winds can cause trees to fall, and this risk can be increased if the tree itself has a degree of internal rot. Gusting winds can aggravate the situation.

Trees can also fall due to vehicular collision.

A fallen tree will most likely fall onto the higher catenary wire before the contact wire is affected. If the tree is so large that it causes the catenary wire to snap, it may take many hours to remove the tree and reinstate the damaged OHW. Even small incidents can take hours to correct, for trains to then resume.

See *Figure 639* for one rather dramatic instance of extensive damage brought about by fallen trees.

Figure 639 - OHW & Train damage from fallen tree/s at Medlow Bath, July 2011

See also *Figure 640* which shows a demolished OHW portal structure, likely brought down by trees (in foreground) falling onto the OHW conductors and overstressing the old structure. Note that the bend in the portal bridge is at the catenary suspension point. The missing conductors for the closest track are shown over on the left.

Figure 640 - OHW Structures are no match for fallen trees

5.5.1.3 Person on Safety Screen

This is not exactly a failure of the OHW itself, but it can bring trains to a stop and it exists primarily because of the energized OHW.

A horizontal safety screen (commonly referred to as "smoke screen") installed on an overline bridge, sometimes attracts certain types of people who seem to think it's OK to venture beyond the fence or other barricade to stand on the screen.

This situation used to typically show up at least once per month in Elec Trouble reports. For one such instance, refer back to the 6th entry in *Table 50*. Discovering someone in this situation normally requires the power to be urgently turned off, which then stops trains, and often involves the police. For some strange reason the horizontal safety screens tend to attract disturbed people – maybe it's the attention seeking they require, but it is an extremely dangerous thing to do (being located so close to the live 1,500V OHW equipment immediately below). Even so, I was once told of a situation where a painter who decided it was easier to paint the outside of the overline bridge from that handy safety screen on the bridge, little realizing how dangerous this really was. (Fortunately, someone noticed this and changed things so no one was hurt.)

Significant steps have been taken recently to provide anti-throw barriers on many bridges, and this seems to have helped enormously to control the problem. This is a brilliant outcome all round – for those people who make bad choices, for police, for those controlling the infrastructure, and ultimately for running train services on time and people getting to where they need to go uninterrupted.

OHW designers are now likely encouraged to avoid using horizontal safety screens and instead use solid vertical barriers (as part of the bridge design). Refer to standard EP-08000007-SP, "Safety Screens for Bridges over 1500V OHW Equipment".

More information is given in *Section 3.2.5.4*, *Secondary Insulation*.

5.5.1.4 Fire

Bush fires are generally bad news for all involved, and this includes anything located within or adjacent to the rail corridor.

If the fire comes close enough to the OHW conductors, it can cause them to anneal, then stretch under their significant tension and eventually snap and fall to track.

Figure 641 - Fire damaged Pole fallen onto Catenary in Blue Mountains (Photo: James Brickwood)

Fortunately, the transit space taken up by the running tracks can provide some small degree of buffering against a bush fire. But the immense radiant heat from a nearby fire can still cause damage at a distance.

Depending on the severity and proximity of the bush fire, various plastic parts, if used in the bays of OHW, can melt with the radiant heat from the fire. (For instance, the nylon or delrin used in droppers.)

Nearby infrastructure can also burn to failure and affect the OHW, including power poles as per *Figure 641*. (Photo from article dated 6 Jan 2020 in *SMH*, taken by James Brickwood.)

5.5.1.5 Rain

The various insulators that safely allow the operation of the OHW at 1500V, are designed to tolerate a certain amount of heavy rain. In fact, periodic rainfalls help wash at least some of the surface of the insulator so that pollution build-up on the surface is minimised or even totally removed, which is good news (but not so inside tunnels where it doesn't rain).

The corrugated "petticoats" provided on the underside of many insulators help by providing a longer current leakage path, and they are also more likely to be dry in certain areas (well, at least that's the intent). For a diagram, refer further back to *Figure 34*.

The aim is to minimise any dc leakage currents across the insulation surface, and reduce the chance of flashover with lightning, etc.

Heavy, persistent rain can also cause the rail corridor land to become destabilised and subside.

If the leg of an OHW structure happens to be located where the land slippage occurs, then the structure's integrity can be jeopardised in a few ways.

Refer to *Figure 642* for a landslip example affecting an OHW structure at Leura in 2020. (Photo from article dated 10 Feb 2020 in *Blayney Chronicle* provided by Paul Toole MP.)

Floods can cause similar problems.

Figure 642 - Land Slip affects OHW Structure at Leura, 2020 (Photos: Paul O'Toole, MP)

5.5.1.6 Hail

I'm not aware that hail damages any OHW infrastructure, but it is possible that the brittle porcelain used in some insulators can be a potential issue. I guess this would depend on how large and intense the hail stones are in the downpour. Even so, small to medium porcelain chips taken out of the insulation, and cracks within the porcelain itself, are unlikely to cause trains to stop. Any damaged insulators would still require replacement at some stage (picked up by routine patrols or when performing hands-on maintenance).

It may be possible that the thin skirts of resin insulators, particularly those with some age or those that are heavily exposed to the sun, at some stage may become brittle and render them susceptible to fracture damage from the impact of hail stones.

5.5.1.7 Flashover

Flashover would typically take place at a 1500V insulator, and this can happen a number of ways. The most usual is lightning flashover – see *Section 5.1.23.4*. But it can also be due to animals stretched over the insulator/s from live to dead (so to speak), or from metallic objects dropped into or blown onto the insulator.

The standards for the 1,500V OHW system require a minimum electrical clearance from live parts to earth or rail potential, to be kept at a minimum distance of 150mm. The theory was apparently that if a flashover were to occur, the 150mm distance cannot sustain the resulting 1500V dc arc, and so it becomes self-extinguishing within a very short period of time. Refer to *Section 2.6* or *Section 5.1.24*.

So, with this minimum 150mm clearance it's likely that there will be much less damage from any arcing than might occur.

5.5.1.8 Pollution

Pollution build-up on the surface of insulators can cause dc leakage currents to flow across the insulation, which may contribute to nearby electrolysis corrosion. This leakage current is likely to be accentuated under moist conditions.

Refer to *Figure 643*, which shows post type insulators located inside a tunnel, with dust contamination (including brake dust from trains) on the surface of insulators built up over a long period of time.

Figure 643 - Pollution buildup on Insulators

It is important that such pollution be periodically removed to prevent even low levels of leakage current from flowing.

5.5.1.9 Salt Water

See "pollution" above.

Also, salt water can accelerate the corrosion of galvanised steel and reduce its life.

5.5.1.10 Hot weather

Fixed-anchored conductors need to cope with hot conditions, meaning reduced mechanical tension in the wire, along with any adverse consequences of this on the OHW system, e.g. low wire (< 4.57m) risking the wire touching the top of a double-deck train, and/or excessive blowout under strong winds risking the loss of pantograph security, etc.

In regulated OHW, the weight tensioners must not bottom out (to ground or other obstruction) when hot.

Hot weather can reduce the amount of power that can be transmitted to trains before *overheating* occurs on the OHW conductors. If the conductor temperature goes above 80°C or 90°C, the annealing process starts and can lead to permanent wire softening damage (i.e. reduced strength for holding high mechanical tensions). Refer to *Section 2.5.8*, *Annealing*.

See *Section 3.1.0.5*, *Thermal Aspects of OHW* for more information.

5.5.1.11 Cold weather

Fixed-anchored conductors need to cope with the high mechanical tensions (stresses) brought on by cold conditions. The tighter catenary can reduce the amount of its sag in a bay and thus reduce vertical clearances from catenary to an overline bridge above it.

In regulated OHW, the weight tensioners must not rise so much as to jam into the pulleys when cold.

See *Section 3.1.0.5*, *Thermal Aspects of OHW* for more information.

5.5.1.12 Dust Storms

See *Section 5.5.1.8*, *Pollution* above.

5.5.1.13 Dry Conditions

The absence of rain can lead to pollution build-up on vital parts, especially insulators (possibly leading to increased dc leakage currents).

5.5.1.14 Vandalism

Just about any small to medium size object can be tossed up to or dropped onto the OHW from above by vandals.

Figure 644 - Shoes in OHW

Figure 644 shows a pair of shoes with their laces tied together, tossed over the 2 catenary wires (it appears one of the shoes is talking). They will likely hang there until a lineworker removes them. Such is life.

But sometimes the OHW can be interfered with in a way that can adversely affect its performance that may not so obvious. For instance, in the above example the shoes add *surface area* which can affect the maximum amount of conductor blowout if located towards the middle of a long bay with strong 130km/h winds blowing. If the track / train / OHW tolerances are already close to the limit in the affected bay, then even a small additional amount of blowout can jeopardise *pantograph security* in that bay – unlikely, but possible.

Many years ago, various OHW porcelain insulators used to be targeted for rifle practice. But the more slender resin insulators at wire run terminations nowadays are not as easy a target as they used to be. Fortunately, Australia's tighter gun control should almost put a stop to this activity now.

5.5.1.15 Vehicular Damage

Vehicles such as cars, trucks, etc. can back into an OHW structure, possibly buckling the mast and maybe causing subsequent failure. Note that some structures amazingly survive a limited amount of damage, and even though the leg may be buckled, the OHW remains held up. But regardless, this scenario should demand urgent expert assessment and repair.

Figure 645 - Bent Portal Leg

Figure 645 is a photo of a banana-shaped portal leg, which was quickly strengthened using a diagonal strut back to an existing guy anchor block (how convenient was that!). This structure remained in service for quite a while until finally corrected. But the altered alignment of the mast would likely have impacted the various runs of fixed-anchored OHW supported here.

Figure 653 (further on) shows a pair of portals that had come to grief when some hinged component from a train came loose and swung into the path of the portal legs, causing the portal structures to collapse.

5.5.2 OHW Failures Due to OHW Condition

The following list shows *some* of the more prominent types of failures of OHW equipment based on its condition. These include direct failures as well as things that can eventually lead to failure if left unchecked.

5.5.2.1 Worn Thin Contact Wire

As mentioned previously, the contact wire can wear thin, especially at various "hard spots" such as pull-off arms, at turnout forking-in points and at section insulators. Refer to *Section 3.1.2.4*, *Contact Wear*.

Such wear can be readily seen in *Figure 646* (right side), which was likely caused at a badly adjusted contact full splice(?). The full-splice fitting tends to hide the remaining thickness of the contact wire which is something to be aware of (as per *Figure 131* back in *Section 3.1.7*).

The reduced cross-sectional area of contact wire will lead to increased stress in the wire at that point. If the wire is sufficiently worn, the resulting stress may eventually cause the wire to locally stretch and then ultimately snap under the ever-increasing stress caused by its reduced area.

Figure 646 - Extremely thin contact wire (at right)

Fixed-anchored contact wire is particularly notorious for this type of failure, as the wire *tension* increases by a huge amount under cold temperatures. This tension intensifies any *hard spots* at pull-off arms causing localised wear, and it also increases the stress in the worn wire. Unfortunately, both these things can work against the contact wire's survival to a ripe old age. Refer also to *Section 3.1.2.5*, *Condemning Size*.

5.5.2.2 Corroded Parts

The majority of OHW equipment that is not live at 1500V, is made from steel that's been hot-dip galvanised (because the steel is relatively cheap and has high mechanical strength), e.g. masts, cantilever frames, anchor brackets, pull-off fittings, etc.

It is imperative that the thick galvanised coating remains in good condition over time so as to continue to protect the underlying steel. Otherwise, rusting starts to take place which is then difficult to arrest.

Sometimes the layer of galvanising can be worn through by continual rubbing or movement against some other item.

In salty or polluted environments, the chemicals in the atmosphere can further accelerate the corrosion process, especially when water is added to the mix.

Refer to *Figure 647*, which shows a missing cantilever frame and damaged OHW at Tuggerah in 2014, when a cantilever (like that shown at next structure) failed, apparently due to a spare link wearing against the top horizontal chain (see Inset).

It was accepted common practice to leave 2 or 3 spare links in the top tie-rod & chain of the cantilever, so that its length could be conveniently adjusted if needed in future (in 50mm increments). The length of spare links dangles, and so can rotate and move about in windy conditions. This OHW was built in 1980, so over the ensuing 34 years this small relative movement occurring every now and then, coupled with the salty or polluted atmosphere, caused wear and corrosion until the affected chain link (see Inset) ultimately failed under tension. Amazing.

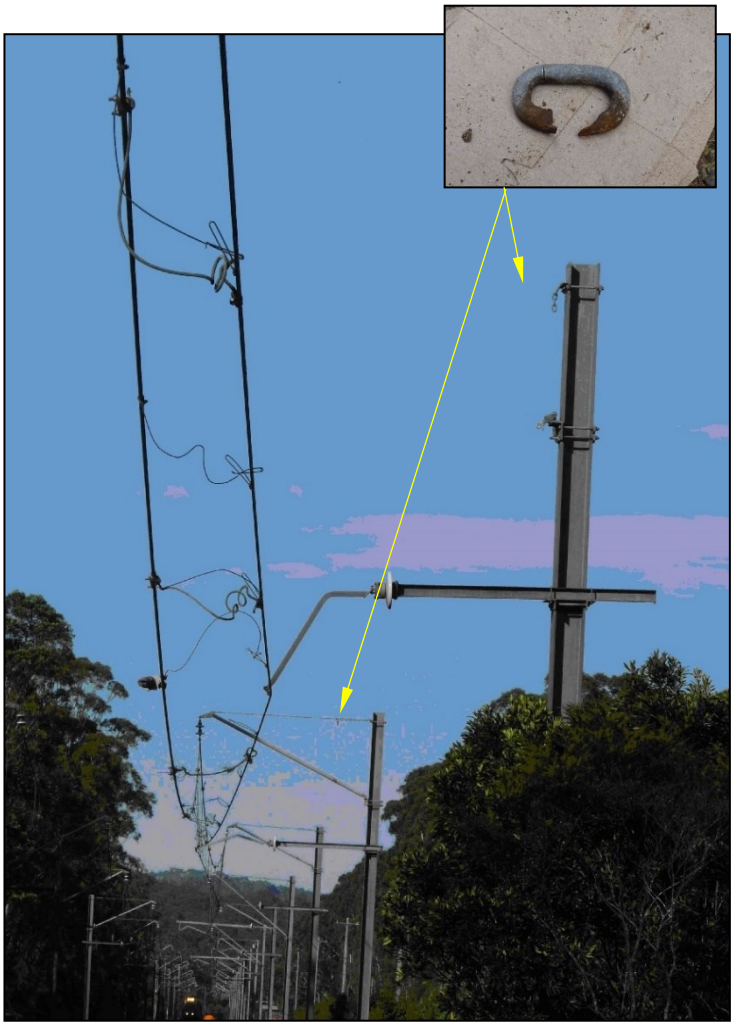


Figure 647 - Failed OHW due to wear & rust on Cantilever top chain

5.5.2.3 Tension regulator weight adjustment

If the tension regulator weight stack is set too low, it can bottom out when hot. And if it's too high, its rope connection to the support rod can jam in the pulley located above it when cold. Also, the guide rod brackets could interfere with the eye-bolt installed in the weight stack.

Use the *WeightSet* spreadsheet program to accurately model each weight stack instance periodically to ensure unimpeded weight travel, to improve reliability. See *Section 3.4.2*.

5.5.2.4 FJs or PJs become restricted

If not properly installed, these jumper wires can become *bar tight* and then impede catenary wire movement under extreme temperatures in a regulated OHW system.

This can come about due to poor installation, with insufficient "U" depth in the jumper wire itself (ideally, they should be 800mm deep to allow full freedom).

Also, the relative positions of the two U-bolts may not be set up correctly for the temperature at that time, or the catenary wire may drift over time. Both these can cause the feeder or potential jumper to be stretched tight at some temperature extreme.

A jumper wire that periodically becomes bar tight can also result in fatigue of jumper wire and possibly their U-bolt attachment clamps. See *Section 3.1.12* for more details.

5.5.2.5 Pull-off arms not set correctly

In a regulated OHW system, each pull-off arm should be positioned to be perpendicular to the track (in plan view) at the design temperature.

This setup is important because the arm rotates horizontally about some pivot point (which is typically back at the mast, or at or near the end of the arm/s). This rotational movement will *alter the contact stagger when the temperature changes*.

If the arm is not set to the correct offset for the ambient temperature, this can adversely affect the staggers at high or low temperatures. This in turn may ultimately lead to loss of pantograph security, which is most likely to occur at mid-bay during extremely windy conditions (where the wire is less well controlled).

Refer to *Section 3.1.0.5, Design Temperature* for more information.

Also refer to *Section 3.2.0.5*, *Stagger Change with Regulated Contact Wire* which has an accompanying diagram showing this situation.

5.5.2.6 Fixed-anchored tensions not correct

A catenary or contact wire that's not correctly tensioned can play havoc under extreme temperature conditions, and problems can take place anywhere in the wire run. Interface areas such as at junctions can be a real concern if the wire is not properly tensioned.

This incorrect tension problem is particularly relevant to fixed-anchored OHW – the simple slip of a vital fitting can alter the tension in the wire run. (But it can also be an issue with regulated OHW.)

The tension should be checked periodically. If any changes are made to the F/A OHW, then the tensions should also be rechecked.

Note:

> There's a tendency to think that a fixed-anchored system behaves like a regulated system, which is an attitude that's far more prominent these days. However, they behave in totally different ways, which is something that can trap the unwary if changes to the OHW are not properly thought through and handled. This was discussed back in *Section 2.10*, *"Fixed-Anchored" is not "Regulated" OHW*.

INCORRECT CATENARY WIRE TENSION

Over-tensioned – can cause the wire to snap; lead to reduced conductor clearances under an overline bridge; cause too much contact hogging in bays; increase the insulator swing at support locations, lead to loss of relative alignment with other catenaries at turnouts; etc.

Under-tension – can lead to excessive catenary wire blowout; can cause the supported contact wire below to belly so much as to touch the roof of a train; can lead to the loss of relative alignment with other catenaries at turnouts; etc.

INCORRECT CONTACT WIRE TENSION

Over-tensioned – can cause the wire to snap (especially since it has a very small virtual span); additional radial load at pull-off arms and their components; etc.

Under-tensioned – most importantly, this can lead to: excessive blowout (and risks loss of pantograph security), as well as increased contact wire ripple between droppers (and consequent pantograph arcing / intermittent supply loss to train), etc.

Contact wire wear - this can occur especially at turnout forking-in points, at pull-off arms, at contact kinks, at contact splices, at section insulators and any other "hard spot", etc.

5.5.2.7 Wires Set Too Close to Earthed Equipment

This sort of electrical clearance issue can happen when adjustments are made to the cantilever (for instance) without checking locally for the required 150mm minimum clearance from live parts to earthed parts.

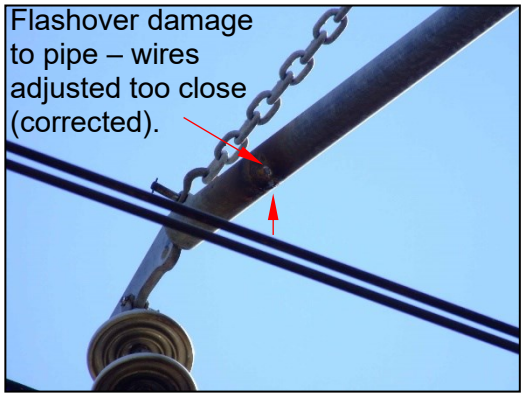


Figure 648 - Flashover damage to Cantilever Pipe

See *Figure 648* for example, which resulted in one or more flashovers and subsequent catenary wire damage that brought the OHW down in 2010 and stopped trains near Beecroft / Pennant Hills for quite a long time until it was finally repaired.

See also *Figure 649*, which shows what happened when someone adjusted one cantilever for catenary height without checking its impact on the nearby wire clearances to earthed cantilever pipe (less than 1 metre away). This happened somewhere on the Illawarra line I believe (Sutherland to Waterfall?).

The new adjusted clearance was estimated at 50mm, when it should be more than 150mm. It's likely that the closer (in-running) cantilever was adjusted to lower its catenary/contact heights, bringing about this problem and also resulting in some unacceptably large heel heights.

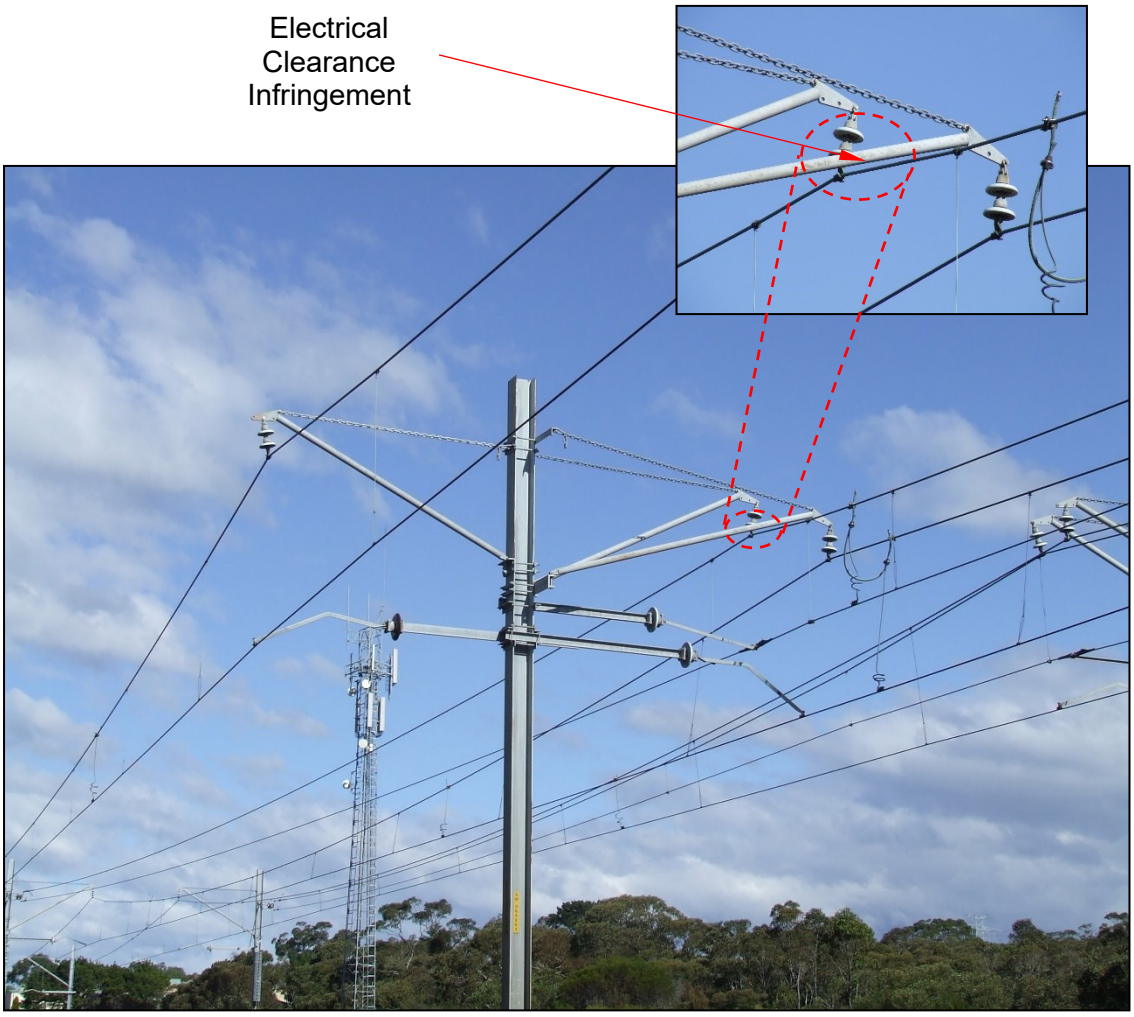


Figure 649 - Adjustments to a Cantilever can affect nearby wire clearances

5.5.2.8 Wrongly Installed Parts

All OHW equipment should be installed exactly as the design drawings call up, unless there are problems in doing so. Any such problems should be communicated back to the design engineer so that corrections can be made (both here if needed, and especially for future benefit elsewhere), or alternative arrangements put in place. But it needs to be managed.

Figure 650 shows a downward view of a post type insulator and pull-off arm, as well as a "raiser bracket" for connecting a span wire (out to hold the catenary). See *Figure 247* further back for its normal use. The span wire wraps around a copper thimble (T11/7) with a single U-bolt clip (463/21) terminating this end of the span. There's meant to be a 16mm diameter stainless steel pin inserted at the top of the raiser bracket that this thimble connects around. But instead, this example shows a bent, rusty bolt (possibly 10mm diameter), with nut and washer, in place of the SS pin. The fact that the bolt is bent is an indicator of the amount of radial and wind loads this span has witnessed over the years, and it's clearly unsuitable. And the rust!

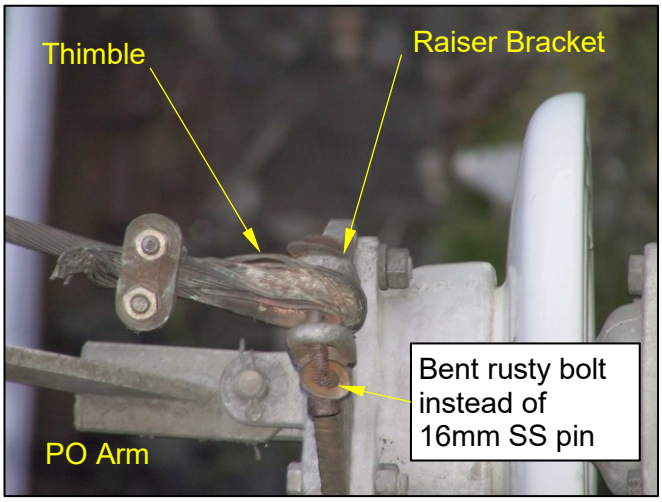


Figure 650 - Top view of incorrect raiser bracket pin installation

I know at times some OHW parts may not be available on the day (for whatever reason), and substitutions are made just to get the work completed. But this is risky stuff, and if it's not checked out, and corrected quickly, it can be forgotten entirely, until something breaks …

But equally important, it's sloppy workmanship, that unfortunately can get copied by others who think it must be okay to do it!

5.5.2.9 Fasteners Become Loose

Obviously, all bolted connections need to be tightened to an appropriate tension, to prevent the connected components from becoming loose. But it's so important that the various fittings installed close to the pantograph path are connected and tightened correctly, because of the amount of *vibration* that can occur daily as numerous pantographs pass through.

Figure 651 is a photo of damage to a twin-contact pull-off arm, showing a contact swivel clamp disconnected from its contact wire. It looks like the arm (with its swivel clamp) lowered into the path of a pantograph and was struck, causing the end of the arm to bend and displaying some signs of black arcing damage.

No doubt this would have caused significant damage to the pantograph also!

Although I'm not sure of the exact cause of this incident, it is the type of situation that can result from having loose fasteners. It is possible that the 2 clamps that tighten onto the upper wedge of the contact wire were not properly seated when tightened, and eventually become loose.

Figure 651 - Disconnected Contact Swivel Clamp on Pull-Off Arm

5.5.3 OHW Failures Due to Interface Issues

5.5.3.1 Track out of alignment

The track's position at any location is defined by its lateral position, its height and its superelevation.

If any of these 3 aspects is outside its stipulated tolerances, it may lead to *loss of pantograph security*. Even a sudden dip in the track can cause a problem with pantograph security. This effect can be best appreciated in *Figure 682* further on.

This problem can be identified by special track inspection vehicles equipped with sensors that routinely traverse the network to pick up problems with the track. RVX-4 was such a vehicle that could identify certain OHW exceedances (e.g. contact stagger and height).

Track position can be checked against a survey TCM (Track Control Mark) plaque, which is usually installed on each OHW structure – mast or portal leg. The TCM information describes the design position of one or more adjacent tracks, in terms of lateral position, (low) rail level and track superelevation.

5.5.3.2 Pantograph in poor condition

Any pantograph in poor condition can lead to the contact wire being damaged, which can bring many bays of OHW down if the train fails to stop immediately when a problem occurs. This could be due to:

- Worn carbon strip down to the metal carrier (causing metal-to-metal wear on the contact wire).
- Missing carbon strip segment or portion (leaving a notched gap that the contact wire can fall into and get trapped, causing further damage to pantograph/OHW). *Figure 652*.
- Loose pantograph frame, etc., leading to the pantograph head going out of alignment and causing it to strike objects (e.g. OHW equipment near its path) or otherwise collapsing.

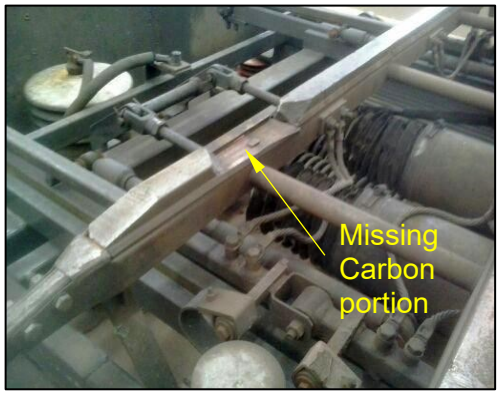


Figure 652 - Missing carbon strip portion

Note:

The damage in *Figure 652* was actually caused by an OHW clamp lowering into the path of this pantograph (travelling at speed). But I include it here because, regardless of how it happened, this notched area can still cause significant grief if a contact wire gets trapped within its bounds and refuses to be laterally released as it tries to zig-zag across the pantograph head – it would likely result in further damage to both OHW and pantograph.

5.5.3.3 Train / Load Clash

Unrestrained train loads and other items on track vehicles are quite able to cause damage to OHW and their support structures.

Figure 653 shows a series of OHW portal structures that were damaged on their left-side leg.

This happened when a mechanism became unrestrained on the wagon and swung out on the left side into the path of the portal legs. (I think it was designed to swing out and lock into position, but only when the train was stationary?)

Figure 653 - Steel Portals can only be so strong (Wombara 2010)

5.5.3.4 Diesel or Steam Train Exhaust

TEMPERATURE

The exhaust gas temperature from a diesel train below the OHW may not necessarily be a problem, but caution is needed if any plastic OHW parts come close to the train exhaust.

A 1988 report of mine included some test results of exhaust stack temperatures from test Diesel 44220 with 2 types of diesel motors.

Measurements were taken by the Pyrometry Section of the (then) Mechanical Branch of the NSW Railways. See *Table 51*.

	Exhaust Stack Temperature (°C)	
Notch	**1. Alco Turbo**	**2. BBC Turbo**
Idle	120	111
1	160	115
2	177	170
3	250	240
4	377	364
5	482	460
6	569	485
7	501	468
8	527	458

Diesel 44220 ; Ambient Temp = 20°C

Table 51 - Measured diesel train exhaust temperatures

Temperatures at idle are a reasonable 120°C, but as the train accelerates through different notches, the gas temperature quickly rises to very high values of about 500°C.

To date, there have not been any problems with this that I'm aware of. The 1988 report (mentioned above) did suggest that some melted Delrin catenary rollers installed under a bridge at Morisset, could have been melted by diesel exhaust – or it may have been as a result of lightning flashover. These rollers are now made from brass anyway.

Contact Wire

The lowest part of the OHW is the contact wire/s, which zig-zag across the pantographs through the bay and are located laterally within about ±350mm from the centre of train.

Any blast of hot gases from the exhaust onto the contact wire could be in a fairly concentrated area (slightly larger than the diameter of the exhaust stack located below it).

If this heat blast strikes the contact wire and causes its temperature to locally rise, the excellent thermal conductivity of the copper wire can effectively draw away the added heat longitudinally *in both directions*, thus limiting the maximum temperature rise to a lower value. This is provided the rest of the contact wire is not too hot (e.g. on an extremely hot day, or when huge currents are somehow being drawn through the contact wire at that time).

Fortunately, the exhaust stack is located well below the OHW – the top of train is about 4.2m, so the contact wire is typically 800mm or so above the train, which is quite a large distance.

Also, the train would more than likely be *moving along* when any of the higher temperature readings to occur (i.e. during acceleration), so the duration of exposure to the higher temperatures should be brief, which should also help the contact wire heating situation.

Plastics

The delrin plastic of the *delrin bar twin dropper arrangement* can be close to the action, but over the past 30 years or so, there have not been any reports of melted parts that I'm aware of. This may be because of the vertical distance from the train exhaust (the exhaust temperature falls quickly with distance). It may also be because, as mentioned above, the train is likely moving by the time the high temperatures are reached, so the plastic is only exposed for brief moments.

The *insulating dropper sleeves* are a retro-fit item installed on the lower loop, and ideally all droppers should now have them installed. They are made from a special nylon, but they too seem to be coping well with exhaust temperatures (probably for similar reasons).

SMOKE

If steam trains traverse the area where OHW is installed, then the maintainers of the OHW need to be mindful of the ability of smoke to build up on the underside skirts of insulators and eventually provide a dc leakage path when wet, to the possible detriment of the system and the surrounds (i.e. electrolysis corrosion). It becomes a failure to effectively insulate.

Refer to *Figure 600* further back in this document, which shows a steam train billowing smoke up onto various OHW parts, and particularly the insulators, which is unavoidable.

In most catenary suspension insulator situations, the corrugated underside of the skirt of the insulators may not receive any cleaning benefit from rain downpours, because the purpose of the skirts is to provide a lengthened and preferably somewhat ***dry*** path across the insulation so as to reduce any levels of dc leakage currents to a minimum.

So, these insulators may need to be manually cleaned from time to time (as per the OHW Technical Maintenance Plan).

5.5.3.5 Pantograph Bridging an "Open" Section Insulator

This adverse situation, of a section insulator parking under and bridging out 2 different electrical sections for a considerable length of time, was mentioned back in *Section 3.6.0.5*, *Damage Due to Pantograph Bridging SI*. The following incident at Flemington in 2000 may be of interest here.

Apparently, the track insulation (to ground) for tracks leading inside Flemington Maintenance Centre was a concern. So, to minimise any resulting electrolysis issues, the nearby Flemington Substation, supplying the several Main Lines, was configured to have a separate supply to the Car Shed, per *Figure 654*.

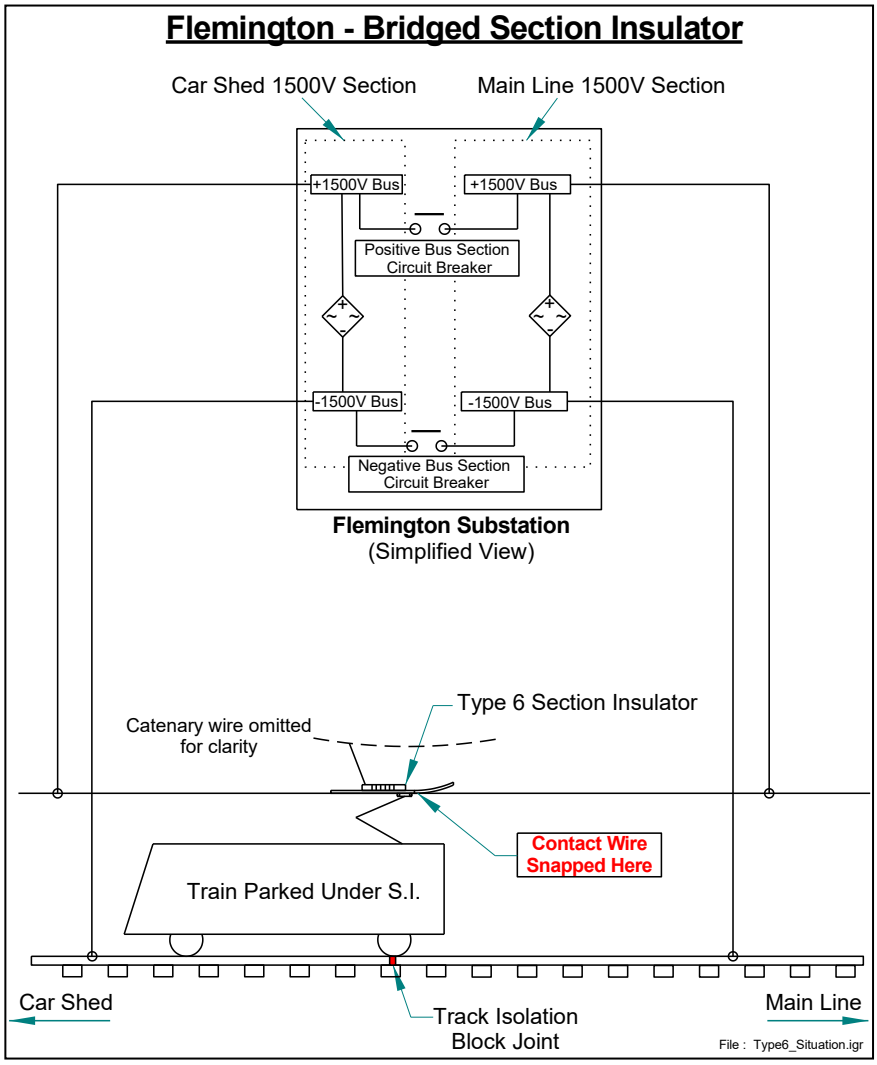


Figure 654 - Pantograph parked under SI at Flemington

This required the installation of a (Type 6) section insulator, as well as a "track isolation block joint" (to electrically isolate the rails of a track) located beneath the SI (shown in the diagram), for various parallel roads leading into the Centre.

While this situation helped the electrolysis concern, it did introduce a potential risk:

> *that if a pantograph stopped beneath the section insulator, in a position that electrically bridged-out the 2 electrical sections via the carbon strips of the pantograph, then the circulating feeding currents (resulting from the various loads of other nearby trains), may overheat the contact wire at the carbon strip connection point/s.*

Even though unlikely to occur, this scenario played out in 2000, resulting in the contact wire either arcing and melting, or overheating and annealing. But either way, the contact wire snapped (under its full tension) and came down, affecting other tracks leading into the Maintenance Centre near the crucial main line area.

Even the rails showed some small signs of arcing at the insulated joint (at some stage), seen in *Figure 655*.

Figure 655 - Arc spatter on rail at isolation joint

The use of a section insulator aimed to minimise the chance of a pantograph parking in a position that bridged out the electrical sections. All good, but …

5.6 RELIABILITY

The Overhead Wiring conductors are the frontline electrical interface with electric train services. It follows that if the OHW conductors fail for whatever reason, there is normally significant disruption to train operations and therefore to passengers (both those on-board and those waiting for the services to arrive).

The cost to restore supply can be quite high, but the total cost (and inconvenience) to the travelling public is likely orders of magnitude higher, and the loss of reputation to Sydney's rail system as a reliable operator can also be significant and long-lasting.

If an OHW conductor fails and is brought down to track, it will affect the track it is serving. However, depending on the situation and how the OHW was designed, it may also affect the adjacent track/s. A good example is the situation of a crossover located between the Up and Down Main tracks. If the OHW fails in this area and affects the crossover OHW, it is most likely that both main line tracks will be affected, and trains will cease operating on both tracks. In addition, it will likely require isolation of both tracks to bring about the repairs needed to fix the OHW.

The time taken to repair the OHW depends on the type of OHW, the severity of damage, the extent of damage (in terms of distance), the convenience of access to the affected area, the availability and response time of maintenance staff to correct the problem, access to spare parts, etc.

Particular emphasis is placed on the peak periods:

- ***Morning Peak*** (nominally from about 6:00am to 10:00am) and
- ***Afternoon Peak*** (nominally from about 3:00pm to 7:00pm)

It's obvious that these are the times when most passengers are affected by any train delays – train operations are at peak capacity, and any request to remove one, two or more tracks for corrective action during this time is normally unacceptable.

It is the morning and afternoon peaks that are the focus for operations reporting every day.

There will likely be more flexibility for rerouting trains for periods outside these hours, but it comes with the understanding that the subsequent peak period/s must not be disturbed.

5.6.1 Independent Registration

In the mid 1980s the concept of *independent registration* was being promoted as a way of minimising the disruption to train operations in the case of OHW failure.

Independent registration requires the OHW to be designed in a way that attempts to keep the OHW equipment that services a particular track, over that track only. In this wat, if a failure happens to the OHW for that track, then only that track is affected. That's the theory.

So, for a number of decades now, independent registration has been mandated for any new OHW designs, and was highly desirable when altering OHW and upgrading some areas.

A good example is the MTS (Metropolitan Track Strengthening) Project – installing concrete sleepers – in the lower part of the Blue Mountains. Here, the OHW had to be checked out and adjusted to accommodate the slightly higher track (resulting in lower contact wire heights). In the process, it was mandated to provide independent registration. This required the removal of all cross-spans at all the numerous mid-bay pull-off locations, and replacing them with shorter track-related spans from a portal leg, or mid-track drop vertical made available by a newly installed cantilever and nose structure.

I understand that the implementation of the independent registration policy has had a huge positive impact on reliability. Its implementation came at a reasonable initial marginal cost, but it provides benefits for running train services into the future.

5.6.2 Maintenance Management

As with most of Sydney's Electrical System (both ac and dc), in the 1990s a Systems Engineering approach was adopted to, among other things, thoroughly assess and document the operating equipment and the way it fails. Then, to put in place the tasks and other support needed to appropriately maintain the infrastructure using the technique of "Reliability Centred Maintenance" (RCM).

This process covered a range of processes and documentation, including the FMECA process (described below).

It was a huge initial effort that was carried out over several years, and as far as I am aware, it continues to be funded to maintain its relevance, especially as things change and new equipment is added.

One of its aims was to ensure that all equipment was appropriately maintained for providing reliable service into the future. This in turn helped justify the costs involved in its maintenance. But there are many other benefits.

5.6.3 Failure Modes Analysis (FMECA)

As mentioned in the Introduction and in *Section 5.4.6*, a "Failure Modes Effect & Criticality Analysis" (FMECA) was carried out in 1992-93 on virtually all of Sydney's OHW equipment. This was required to help establish the Technical Maintenance Plan which was under development at the time across most of the rail engineering disciplines. Similar work was also being undertaken by other aspects of the electrical discipline, including HV aerial lines (transmission lines), HV cables and the gamut of substation equipment. It was also undertaken in the track, civil and signalling areas.

The challenge was to identify the common fundamental OHW systems and equipment in use, then determine the various "unique" systems that only applied to certain districts – this was achieved by visiting each district, in turn, until all equipment was covered.

The resulting equipment was *numerically structured* (using the "EP-08" prefix for OHW). This is where the structure (as shown on the front page of this document) came from, viz.: 1 = Conductors; 2 = Support & Registration; 3 = Support Structures; 4 = Anchors; etc.

All equipment types were then each analysed in terms of:

- *The way it fails*,
- *How to fix it* if and when it fails (corrective action),
- *How to prevent it failing* in the first place (preventive action),
- What *spares and consumables* are required to prevent the failure, or to fix it when failed,
- The *criticality* of the equipment failure to the OHW system and ultimately to the rail system (in terms of safety/environmental/operational/economic/hidden), and thus its importance and periodicity for checking its condition (how often to examine for evidence of potential failures).

A sample of one particular original FMECA analysis output is shown in *Figure 657*. This shows the first page (of 13) documenting the analysis of the various ways a *Single Contact Wire* (in *fixed-anchored* system) can fail, what to do about it as it deteriorates or if it fails, how to prevent failure, etc. There were 91 such analyses needed in order to cover the entire range of OHW equipment types back then, and a few more have been added since that initial

work was undertaken, e.g. new equipment introduced into the system. *Table 10* shows where this particular FMECA analysis lies (on equipment EP-08060000). Refer to other Tables in *Chapter 3* of this document for an idea of the range of other equipment types that were analysed. I remember when doing this, there were a lot of common failure modes, but they all had to be documented as per *Figure 657*.

A main outcome was a set of "Service Schedules" that identified how to properly maintain each type of OHW equipment. The schedules were to be applied at defined intervals or according to events (such as post-storm or post-bush fire). They explain how to examine the equipment, what to do if certain conditions were observed, etc. Supporting publications were written to help explain further how to carry out the various tasks for more effective and consistent maintenance. These documents included a description of the equipment and how it worked, and the servicing required to be carried out, especially giving detailed descriptions of how to fix problems if and when they occurred.

I understand the whole point of the undertaking was to determine the best way of maintaining the OHW assets, that results in the highest level of reliability while minimising the cost of ownership. After all, it was "Reliability Centred Maintenance".

Note that much more work has been carried out since the initial setup, by a group dedicated to progressing the process and keeping things up to date. I understand all sorts of information is available, including costings, e.g. the *Maintenance Requirements Analysis Report*.

5.6.4 OHW Renewal Program

Since the mid 1980s Sydney has embarked on a major program to update and upgrade the existing OHW systems at various locations, so that equipment considered life-expired was brought up to date and modernised.

This action required the OHW to mostly be renewed as *regulated tension OHW*. Along with this came the imperative that it be *independently registered* to help improve reliability and reduce any disruptions to train operations caused by OHW failures or outside failures that led to OHW damage (e.g. damaged pantographs, fallen trees, tall vehicles snagging the wire at level crossings, etc.).

Figure 656 is an example of an old rusty OHW structure at Strathfield being progressively removed, having been recently replaced by a shiny new structure (with 2 OHW switches and supporting new regulated OHW above all 6 mainline tracks).

Figure 656 - Example of Old OHW Structure being replaced by a new Structure

Figure 658 shows the status of the network in this regard, as of 2010/11 (which unfortunately is quite a bit out of date, but gives an idea of the extent of OHW improvements).

Tech Maint Code	EP-08-06-00-xx	System Criticality	ANALYSTS
Item / Assy Name	Fixed Anchor - Single Contact OHW	S - Safety ; En - Environ ; O - Operat	FitzGerald / Anderson / Thurtell / Allotta /
Part No / Drg No		E - Economic ; H - Hidden	Turner / Rowe / Popovski / Toms / Jeffs
FUNCTIONAL DESCRIPTION	1. Transmits power at a nominal 1500V DC. 2. Provides a mechanically continuous overhead path for pantographs under specified operating & climatic conditions. 3. Keep components clear of vehicle operating envelope.	O/M - Operator Monitored Red. - Redundancy SD - Secondary Damage	Cur. - Current Task Val. - Task Validity PerC - Current Task Period PerN - New Task Period Task Type P - Preventative S - Surveillance C - Corrective

Part	Failure Mode	Cause Of Failure	Local Effect	OM	Red	SD	Crit.	Tasks	Cur	Val	Type	PerC	PerN
1. Contact wire	1. Mechanical separation	1. Worn below structural strength (especially at bridges, arms, SI's, splices, restricted droppers, etc.)	Secondary damage from train impact	N	N	Y	S	1. Examine for wear beyond condition limits	Y	Y	S	2 wks	6 wks
								2. Fit wearing strip where appropriate	Y	Y	C	AR	AR
								3. Renew wire	Y	Y	C	AR	AR
								4. Identify & remove cause if appropriate	Y	Y	P	AR	AR
								5. Measure contact wire thickness	Y	Y	S	4 yrs	8 yrs
		2. Annealed wire reduces strength (due to overcurrent)	Secondary damage from train impact	N	N	Y	S	1. Examine for annealing in identified hot spots	N	Y	S	-	TBA
								2. Renew Wire	Y	Y	C	AR	AR
								3. Upgrade OHW for heavier current	Y	Y	C/P	AR	AR
		3. Annealed wire resulting from local fire	Secondary damage from train impact	Y	N	Y	S	1. Examine for annealed wire after fires	Y	Y	S	After fires	After fires
								2. Renew Wire	Y	Y	C	AR	AR
	2. Contact too low	1. Excessive catenary sag	Contact infringes vehicle envelope	N	N	Y	O	1. Examine for low contact height	Y	Y	S	6 mths	4 yrs
								2. Identify & correct cause of excess catenary sag	Y	Y	C	AR	AR
		2. Track too high	Contact infringes vehicle envelope	N	N	Y	O	1. Examine for low contact height (RVX-4 ?)	Y	Y	S	6 mths	4 mths
								2. Identify cause & advise civil section if high track level	Y	Y	C	AR	AR
								3. Raise OHW to gain necessary clearance, if required	Y	Y	C	AR	AR
								4. Redesign to increase OHW clearance to track	Y	Y	P	AR	AR
		3. Fallen object on OHW	Contact infringes vehicle envelope	N	N	Y	S	1. Examine for fallen objects on OHW	Y	Y	S	When advised	When advised
								2. Remove object from OHW	Y	Y	C	AR	AR
								3. Repair OHW & check clearances	Y	Y	C	AR	AR
		4. Detached droppers	Contact infringes vehicle envelope	N	N	Y	O	1. Examine for detached droppers	Y	Y	S	2 wks	6 wks
								2. Reconnect / replace detached droppers	Y	Y	C	AR	AR
	3. Contact stagger outside tolerance	1. Track outside tolerance	Pantograph & OHW damage	N	N	Y	O	1. Examine for excessive contact stagger (RVX-4?)	Y	Y	S	6 mths	4 mth
								2. Identify cause & advise civil section if	Y	Y	C	AR	AR

PUBLICATION: EP 000000 FM Failure Modes Effect Criticality and Task Analysis File: FMECA-08060000.xlsx Date: c.1993 Page 1 of 13

Figure 657 - Sample FMECA Analysis: Single Contact Wire (Fixed-Anchored)

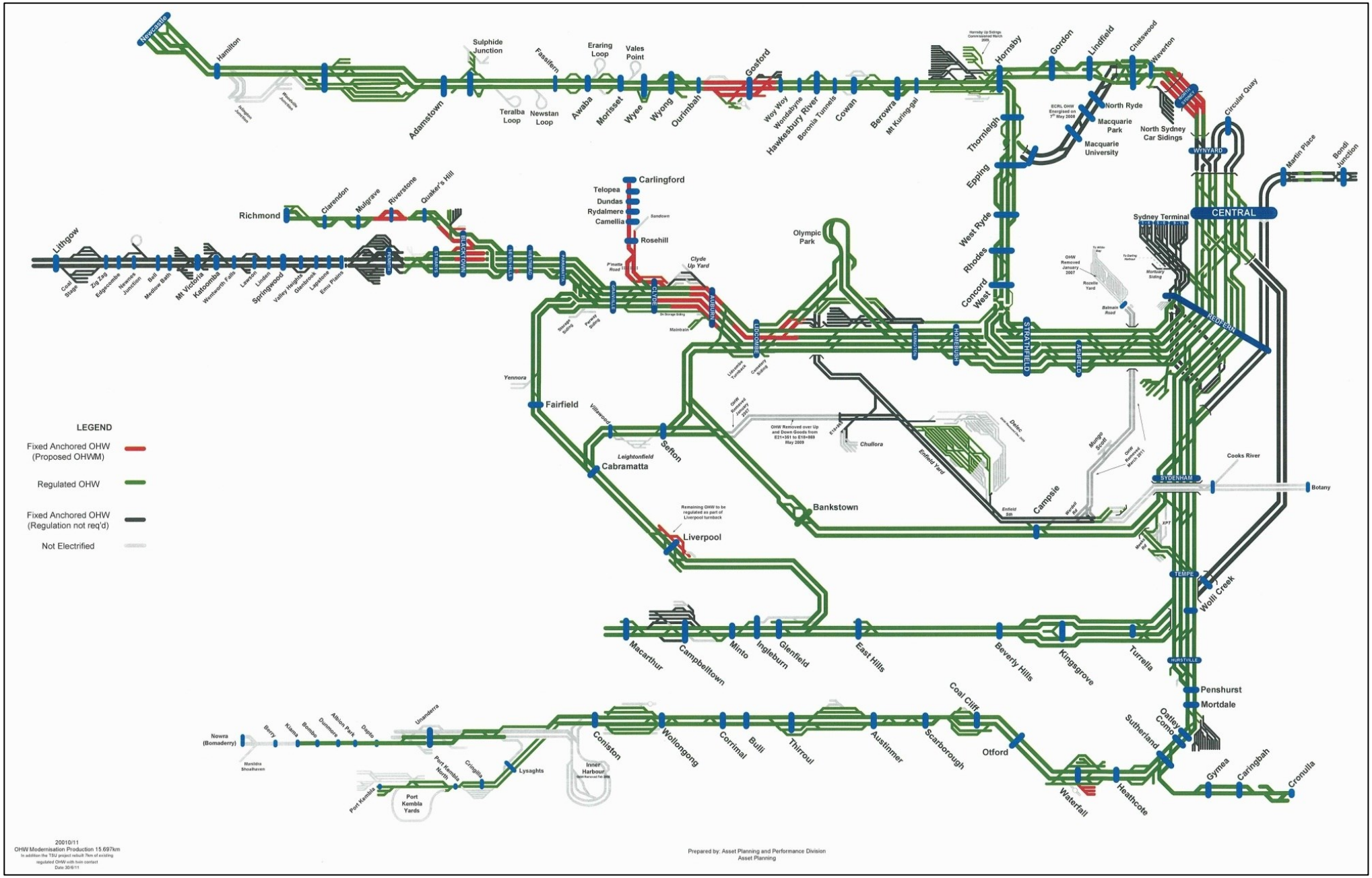


Figure 658 - OHW Modernisation Program Status at end of 2010/11

5.7 SOME SAFETY ASPECTS

I'm hesitant to delve too far into *safety*, because although it's extremely important, it's a *specialist area* and it requires to be dealt with as such. And safety can cover many aspects, including: personal, office, electrical (traction system), work practices, work site, on-track, etc. …

I offer just a few thoughts though, as they relate to the OHW system.

But the relevant Standards must be adopted for the latest approach to safety.

5.7.1 Electrical Safety

Although there will be other aspects to safety, the following 2 types of "electrical" safety are of significant concern here:

- *Electrocution*. This can be from *direct* or *indirect* contact with 1500V, allowing even small currents (milliamps) to pass through the body for short periods (milliseconds), to cause significant injury or death (especially if the current passes near the heart). This includes addressing "touch potential" and "step potential" issues, e.g. standing on an equipotential mat when operating a switch by its handle (that's solidly bonded to the mat).
- *Damage*. This is mostly to surrounding infrastructure, such as bridges, buildings or any other structure that, if corroded by *dc leakage currents* for instance, can collapse and injure people. It can result from even small dc currents (micro or milliamps) passing over a long period of time, or by larger dc currents over shorter times (such as caused by some electrical fault on the system). It can eventually erode the strength of structures (e.g. corroded steel reinforcing in concrete), and lead to structural failure (collapse or other).

5.7.2 The Nature of the dc Supply to OHW

The nature of the electric current supplied to Sydney's trains – its sheer *magnitude* and its *waveform* (dc) – can both present potential problems when trying to protect people and the nearby infrastructure. The concerns are described below.

5.7.2.1 Magnitude of Current

To help put the sheer magnitude of dc current in Sydney's electric traction system to supply trains into perspective, it's useful to note that the electrical system in a typical house employs 230V ac (was 240V) or 3 phase 400V ac (was 415V) at 50hz, with currents of up to 10 amps or even 15 amps from power outlets. So, a normal single-phase power outlet might be able to deliver 2.3 ***kilowatts***. (The above voltage changes were introduced not so long ago to bring Australia into line with European standards).

In order to deliver the ***megawatts*** of power required to supply electric trains at the relatively low level of 1500V, it's necessary to deliver huge levels of dc current through the OHW conductors, of the order of 3,000 amps or more! (Power = Volts × Amps). So, this current is about 300 times the normal maximum household current. (Note that the above 3,000A current is total for the train – so an 8 car consist would demand something like 750A for each of the 4 power cars. Note also that the maximum current is only drawn for short periods, usually during rapid acceleration or when climbing step track grades.)

Maybe also bear in mind that, for instance, a typical domestic electric arc welder (older technology using a transformer), can operate from 230V, but has a transformed welding voltage of only about 15 to 20 volts or so, and a current of about 100 amps. The voltage drops when the arc is struck, resulting in about 1kWatt of power in the arc, but this can

readily melt (weld) steel, and emit bright blinding light in the process. (The plasma in the arc can reach temperatures higher than those on the surface of the sun.) So, in contrast, the current and power to the trains is absolutely huge and so it needs to be well controlled and well protected!

The important things to understand are that:

- The huge dc current of the 1500V traction system can cause immense damage to unintended things if it finds alternate conductive paths, at even low current levels.
- If an arc is established somewhere in the OHW system, it needs to be quickly extinguished before major damage occurs (read "quickly" as much less than 1 second).

5.7.2.2 Nature of "dc" Versus "ac" Current

An *ac* (*alternating current*) supply has a sinusoidal voltage waveform that crosses zero volts twice in every 50Hz cycle – from a varying positive voltage (and current), through zero, to negative, then through zero again. So this zero crossing happens 100 times a second or every10mSecs.

When switching *off* an appliance that's connected to household 230V, generally speaking, the supply current is naturally interrupted (isolating the circuit) when the sinusoidal current passes through a "zero crossing" point. These household switches are normally designed to withstand some small amount of arcing, which can take place as the switch contacts are opened when drawing some current. The arc can continue as current is drawn, up until the next zero crossing, whence it should extinguish. Or it can be extinguished if the arc rapidly lengthens and becomes so long that it can't be sustained. This happens within the half cycle – 10mSec.

In contrast, the supply to OHW is *dc* (*direct current*), and so it has no such current "zero crossings". This makes it difficult to extinguish a dc arc, and the larger the current, the bigger the problem it is to reliably extinguish the resulting arc each time the switch is opened.

With current flowing in the circuit, a dc arc can usually be extinguished, either by:

- Turning off the circuit, using a purpose-designed *dc circuit breaker* that's designed for quenching large arcs during opening (back at the substation and/or sectioning hut), or
- Lengthening the arc distance so that the arc can no longer be sustained, e.g. using *arcing horns*. These can be found on the Type 5 SI, and the Type 6 SI (if arcing horns have been installed for the reverse train running direction), and some 1500V switches have arcing horns in case the switch is inadvertently opened under load, creating an arc that needs to be quickly extinguished (e.g. seen on switch in *Figure 438* further back).

Modern dc circuit breakers can use techniques such as forced arc lengthening, arc cooling and magnetic blowout coils, etc., all in an effort to stop the current flow as quickly as possible. To this end they are normally quite successful (with tripping times in the order of 20 or 30 milliseconds). They are often called "high speed" dc circuit breakers for this reason. I understand they are typically expected to handle a prospective fault current up to 8kA, and an initial rate-of-rise of 250kA/sec. Refer to *Section 6.1.1* for more.

If the arc cannot be extinguished quickly, and is unseen by any other protection, it will progressively melt (destroy) the equipment where the arc (fault) occurred, until the arc current path becomes so long (e.g. due to melted contacts), that the arc can no longer be sustained, as per the following example.

EXAMPLE: COMO, 1990

A good example of how out-of-control high dc current can destroy things, happened at Como in 1990 (which I helped to investigate and report on). But this happened on the 1500V

negative return part of the circuit – the track. A 450mm length of one rail completely melted – refer to *Figure 659* (taken from the report – pardon the poor B&W image).

Basically, a number of heavy-gauge copper cables were cut and stolen from various track impedance bonds at 4 separate locations in the area late at night. These cables electrically bridge one rail section of a track through an impedance bond to the next rail section, across an "insulated rail joint" (IRJ), as required for the signalling system in that area. At substations, the cables connect the 2 rails of each track to an impedance bond which is then connected to substation negative 1500V. Refer to *Section 6.2.1.15* for tie-in bonds.

The disconnection and removal of cables meant that the insulated rail joints that the cables were meant to connect across, were instead open circuit – with just a small isolation gap of a few millimetres between each of the sectioned rails, per *Figure 655*. (The impedance bonds are apparently meant to allow dc current to pass, but prevent the superimposed 50Hz signalling currents from flowing into the next track section, as required for the operation of the signalling track circuits.)

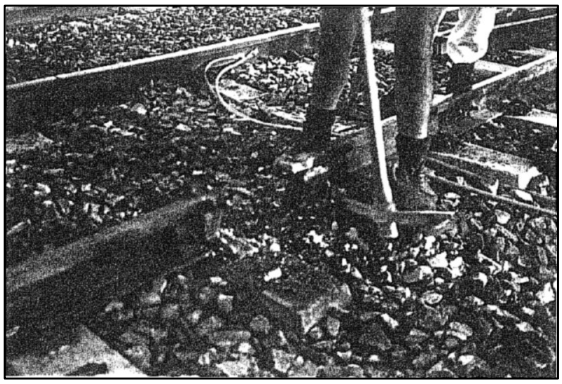


Figure 659 - Melted Rail at Como

It was argued that the removal of these vital cables – notably outside Como Substation – caused the traction rail to be totally isolated from the nearby substation negative.

Later that night, a 3,100 tonne electric freight train (4 × 86 Class locos with 31 wagons) headed south, crossed the Georges River Bridge and passed a (now disconnected) IRJ into the (now isolated) rail section at the southern end of the bridge. Since Como Substation negative connection was missing, it was unable to supply a negative return current, so the supply needed to come from Hurstville Substation located a few kilometres further towards Sydney.

The train travelled through with each wheel shorting out the gap across the IRJ at the bridge abutment, but an arc would have been established here as the last wheel of the last carriage passed the joint. To power the train the arc only needed to be established across one of the 2 IRJ gaps for that track – this is because the voltage drop across an arc is typically only small (guessing 20 volts or so, depending on the length of arc), and may not be enough to maintain another arc on the opposite rail.

The arc was then sustained by the constant power (current) demanded by the freight train, which in turn, allowed current to continue to be supplied to the train that was, by then, powering up the nearby steep gradient heading south – until it came to rest quite a distance away from the substation. During that time, the arc had progressively melted more of the rail, and consequently the length of the arc increased in the process.

The train stopped just short of Jannali Station – the reduced voltage to the train (due to the voltage drops of both OHW and track resistance, and also that of the extended length of arc) likely caused the train's on-board "low-volt" relays to trip, which ultimately stopped the train. Or maybe the arc became so long that it could no longer be maintained, thus opening the circuit (not sure).

The arcing, which established across the insulated rail joint, eventually *caused a 450mm length of one of the steel rails of the track to totally melt*, and the steel rail disappeared as slag into the ballast and down the embankment – *Figure 659* (the corresponding IRJ for the opposite rail seemed unaffected, as can be seen near the far left of this photo). Had a train followed and not noticed the melted rail section, it would likely have been derailed, with huge repercussions. (The thieves would not have expected this as a consequence of their actions!)

Fortunately, someone woke up during the early hours and complained to a local TV station about a mysterious bright light disturbing their sleep! They immediately informed police.

The dc circuit breakers didn't trip because they were seeing a normal load current (not a fault). It's interesting that the train powering up the hill drew the heavy current that sustained the arc, which in turn completed the circuit and allowed the train to continue to power up the hill for a reasonable distance.

The whole point to this example is to give an appreciation of the level of *damage* that can be caused by dc arcing *if left uncontrolled*. In this incident, a long 450mm section of thick 60kg/m steel rail was melted, and it was caused by a huge level of uninterrupted dc current (of a few thousand amps) which was arcing across an insulated rail joint for what would have been only a few minutes duration. Of course, had the impedance bond cables here and elsewhere not been stolen in the first place, this arcing would never have taken place.

5.7.3 Current Protection Circuits

These days "earth leakage detection", if installed in a house, can be used to detect if any ac current is diverted away from its intended circuit. In such cases the leakage current imbalance to earth is detected and supply is immediately tripped to minimise damage or injury.

Similar techniques apply to the high voltage ac network, employing "earth leakage detection". And there's "directional overcurrent protection" as well, and even "differential protection" can be set up to discriminate genuine faults and quickly clear them from adjacent substations.

With Sydney's 1500V dc OHW system, there's no such sensitive dc current leakage detection circuit to provide a safer environment, nor differential protection (although I think there was some talk about the possibility of some such system years ago).

I may be wrong, but in terms of electrical protection, the dc circuit breakers can still only trip in 2 ways: *overcurrent* and *rate-of-rise* (of current).

Overcurrent protection is as its name suggests, and the trip levels are set at around a massive 6,000A (to avoid "nuisance" trips).

Rate-of-rise protection (or *Delta-I* protection) monitors the rate that the dc current increases, and can predict that a fault is likely occurring well before it reaches the above overcurrent setting. In this way, it can take action sooner to trip the breaker and isolate the circuit, to reduce the possibility of any damage (or degree of such). Note that a compensating mechanism needs to be employed to desensitize the Delta-I relays in a feeding overlap. This is needed so that when the first pantograph on a train passes through the overlap and heavy current is suddenly detected in the next electrical section – a rapid rate-of-rise – then the circuit is desensitised so that this breaker does not trip.

The unfortunate thing about the OHW system is that the 1500V exposure isn't contained to any large degree. From a substation, the 1500V connects to the OHW conductors which can radiate out for many kilometres in all sorts of directions, in a mostly *exposed* environment.

However, the good thing is that almost all of the extent of OHW is located above a track and is contained within the railway operating envelope on railway property where there are fewer people (which is controlled mostly to avoid people being run over by trains). If the conductors fail and fall to ground, they should hopefully strike the rail or other rail-connected equipment and trip the dc circuit breakers. This is the main reason why a policy was adopted (~1980s) of installing auxiliary feeders close to track and not have them pass over land well away from the track. (Installing 1500V cables with conductive screen would be a sensible alternative in this case.) See *Section 3.1.0.5*, *Auxiliary Feeders*, and *Section 3.1.1.5*, *Location of Auxiliary Feeders*.

To help out in this system with limited types of electrical protection, the best approach seems to be to keep people and things well clear of any 1500V. It makes sense to do this anyway.

The main concerns are where infrastructure is located above the OHW (such as at overline bridges), and therefore can be in close proximity to the live 1500V conductors (and maybe even the S&R equipment). In these cases, steps are normally taken to *isolate* people and other services from the live conductors, e.g. by installing barriers. A horizontal safety screen is also considered in these situations, although unfortunately its bonding can cause its own problems too (per *Section 3.12.0.5*, *To Bond or Not to Bond?*). Recently, there's been an organisational push to install large vertical screens or barriers onto bridges (so-called "bat wings" or the like, per *Figure 259*) to prevent access – a brilliant move that solves all sorts of problems!

5.7.4 Electrical Permits

All work on track requires the workers to be inducted onto site, to become familiar with the likely hazards of the area and to understand the scope and nature of the work to be performed.

Traction line workers need to also sign onto an Electrical Permit before any work can commence on the OHW. It is vitally important to know the *safe work area*. Obviously training and accreditation are key requirements to help keep people safe when working.

I won't say any more on this, as "Rail Safety" and "Electrical Safety" are specialised areas, which are subject to change over time as improvements are made. In this regard …

The specific requirements of Sydney Train's current *safety system* must be understood beforehand, and adhered to, when carrying out of any work on any part of the OHW system.

5.7.5 Conductive Tools Near OHW

There are a number of situations where conductive tools can present a safety concern when in close proximity to live OHW conductors or equipment.

Long objects are potentially hazardous because, unless their position is well controlled, they can unintentionally swing into the OHW and transfer 1500V to the person holding or operating the equipment. Not a good outcome.

For instance, using metal ladders on station platforms can lead to problems in this regard, and they are therefore usually banned. So, approved timber or fibreglass ladders can be an option.

The humble steel measuring tape can also be a problem if it nears the live OHW equipment.

EXAMPLE: MORTDALE CAR SHED

There was an incident at Mortdale Car Shed where a contractor was measuring along a steel pipe located above a track, to install sprinkler heads (even though timber barriers were erected to prevent such access). The pipe was located near and above the live OHW inside the shed.

Unfortunately, as he was retrieving the steel tape measure (which was extended about 4.4m), it buckled (as they tend to do), and it swung down onto the live OHW conductors 1.4m further away – tape measures can be notoriously unpredictable in this way! It was likely that the bright flash and loud noise startled him and caused him to fall 6m to ground, but fortunately he survived (there were no obvious burn marks). The steel tape almost vaporised, and what remained were very short, burnt segments that were totally unrecognisable. In a sense he was lucky that the tape did this, and that he also fell (?), both actions of which then isolated him from 1500V. Had this separation not happened, the dc circuit breakers may not have tripped, resulting in a bad outcome because he may not have been able to release himself from 1500V.

People often don't take the time to analyse the potential hazards – the "what if" scenarios. However, sometimes they do, but sadly they seem to accept the risk anyway – there was a barrier erected to prevent access here. It's likely a case of the "it won't happen to me"

syndrome. In this case he was extremely lucky to survive that situation (although who knows what the long term nature of the injuries might be).

EXAMPLE: ADVERTISING BILLBOARDS AT STATIONS

Replacing the advertising artwork on station billboards, with adjacent 1500V OHW energized, can sometimes be hazardous and may infringe the electrical safety clearances in many locations if the OHW was left alive (even with the use of non-conductive ladders).

A good solution to this issue is to use new LED/LCD advertising screens (which are becoming more prominent throughout the network anyway). Once they're installed there's no need to send someone out to update the graphics (and it's probably an advertiser's dream to be able to readily change the display contents, and audio/video brings another level of interest for the multitude of station dwellers).

5.7.6 The Travelling Pantograph

Sometimes the OHW conductors can seem so far away as to inconceivably pose a hazard to people. However, when a pantograph comes along, this clearance can be reduced by 1 metre or more, because the edge of the pantograph can bring the 1500V potential temporarily much closer – a case of *transfer potential*.

A good example would be a set of stairs located immediately next to the train corridor, with steps leading up to a pedestrian overbridge or the like, as depicted in *Figure 660*.

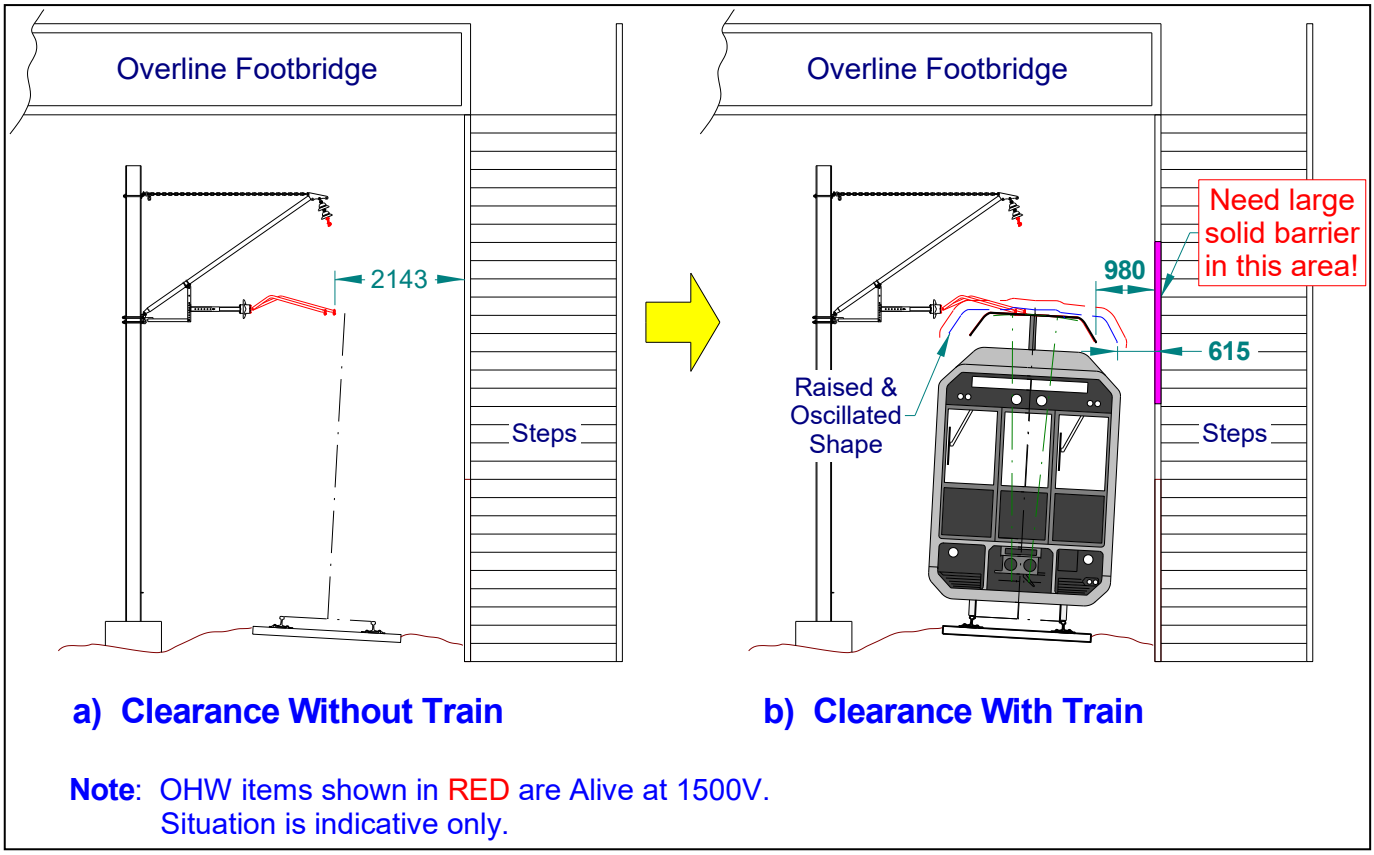


Figure 660 - Transfer Potential – hypothetical example at footbridge

This diagram demonstrates a theoretical situation where the steps up at a footbridge are located immediately next to the rail corridor, and unfortunately the track is also located close to the boundary – see Diagram a). Note also that the direction and amount of track superelevation makes the clearance to the boundary at the pantograph height even closer.

Even though the trains need to be clear of the boundary (including the stairs in this case), there may also need to be a *solid barrier* of suitable length and height installed at a level starting well below contact wire height and rising up as far as needed, to prevent the risk of someone coming within 1m of the *edge* of the train pantographs as they pass through. This is seen in Diagram b).

In this example, the clearance from fence to *live* equipment is reduced from 2,143mm down to 980mm when the pantograph appears – this is a reduction of 1,163mm! Note that this 980mm clearance is reduced even further, down to 615mm to the *Raised & Oscillated* pantograph.

So, the pantograph can readily pose a transfer potential issue. The normal perceived clearance might seem acceptable, but a pantograph can suddenly appear and dramatically reduce the electrical clearance to an unacceptable degree.

Designers in particular need to be aware of this insidious character of the pantograph, and put in place mechanisms to prevent close approach by people, to avoid possible electric shock consequences. (It's not that obvious that there might be a problem.)

For more details on the requirements for dealing with this type of situation, refer to Standard EP-08000007-SP, "Safety Screens for Bridges over 1500V OHW Equipment".

Note that the pantograph can also be a problem inside tunnels or in other restricted spaces. The contact wire controls the pantograph height. So, when services are mounted to the tunnel wall just above the level of the top of train, the pantograph position should be known in order to achieve the required 150mm minimum diagonal clearance from edge of pan to services (in its *Raised & Oscillated* position). Refer to *Section 6.4.1* and its *Figure 703* for more details.

5.7.7 OHW Materials

Sometimes the OHW fittings can cause harm if workers are not familiar with their characteristics. This is particularly true if the equipment is somehow damaged, so things like sharp edges resulting from damage can unexpectedly cause cuts to the skin, e.g. the catenary and contact wires which can have sharp edges if cut through with hydraulic shears.

Probably a good example happened at North Sydney in 2013 during an OHW rebuild project. As I understand it, staff were removing an old porcelain post type insulator from the tunnel ceiling, and the stubborn nuts proved difficult to remove with a spanner. So, a worker swung a hammer onto the end of the spanner. But the hammer deflected onto the porcelain, which then shattered and sent a razor-sharp porcelain shard into a worker's neck, causing lots of bleeding as he was assisted away from site to hospital.

The normal protective gear was worn – hard hat, safety glasses, safety boots and possibly even hearing protection. I guess no one expected the hammer to deflect from its intended path, nor for the porcelain to shatter as it did, nor that a porcelain shard could be that sharp. And the chances of it striking the unprotected neck of all places!?

Hopefully it would have given a new appreciation of the benefits of wearing full protective gear (whatever that makeup needs to be in different situations). This incident should hopefully have been communicated to all others performing similar work on the network.

It pays to do "what if" scenarios, to hopefully anticipate some of the possible adverse outcomes of an activity, and prepare for them just in case. In the above situation, maybe if the insulator was totally covered with a thick rag, it would be less likely for the insulator to shatter, and if it did, the shards should be captured by the rag. Or wear a full face shield?

But in the end, it requires workers to know the character of the OHW equipment and its various components – in this case the porcelain. Experience is a wonderful thing sometimes.

5.7.8 Smoke from Burning Plastics

In certain areas, especially where ventilation is limited such as inside tunnels and stations, it's important to consider the health risks associated with the burning of any materials (e.g. plastics) that may be used in the OHW system.

Such a burning event may be caused by a fault on the OHW system itself, or from the nearby infrastructure, e.g. a fire on a train (although it would have its own problems in this regard).

These days, the design of any new OHW in such a relatively closed environment needs to include a risk assessment, and bring about any necessary changes to ideally remove or to minimise the probability of any such risk and hazardous consequence.

5.8 TRAINING

Training is one of the more important aspects to any kind of business, and work on the OHW traction system (with its many idiosyncrasies) is definitely no exception.

Not knowing a lot about the training side of things, I offer a few comments only (as they relate to OHW).

Training helps provide people with the skills and understanding they need to properly carry out their work, including (but not limited to):

- An understanding of the *fundamentals* of what they're meant to be achieving. Depending on the type of work, this may require them to be exposed to the theory and various other aspects of the OHW system, in terms of design / construction / maintenance / electrical operations / electrical safety / etc.
- An appreciation of the various physical *interface issues* (with track, civil structures, signals, train operations, the environment, etc.)
- Appropriate hands-on exposure to the OHW system, in order to gain some relevant practical *experience*.
- Etc.

In the past, training for OHW construction and maintenance staff was provided by the Training School (at Chullora, Petersham College, etc.). This training provided new staff with the basic knowledge and some practical experience, as required. And importantly, it included exams to test that understanding. It also provided refresher courses in order to maintain the skills, notably as equipment changed or approaches to the work changed in time, etc.

The massive amounts of planned new OHW infrastructure, over the past few decades, has required considerable additional resources – young and old – and in a hurry. Some of these people were needed to design OHW, and more were needed to build it.

The real concern here was that those staff who were new to Sydney's 1500V dc OHW system and/or to fixed-anchored OHW, even if experienced in some other rail organisation, may not fully understand the various quirks, and hence may inadvertently do something that's not appropriate to this system.

This is where training was and remains absolutely essential, to try to ensure that things don't get designed and/or installed in a way that jeopardises train operations, or that introduces safety issues, etc. The OHW is a fairly tolerant system and unfortunately, some mistakes can take many weeks or even years to present themselves, often to the detriment of train operations. This time delay can make "learning from the mistakes" unlikely, and so they can get repeated elsewhere.

And I've mentioned earlier in this document, that bad habits seem to get noticed and then replicated by others, much easier than good habits do. (I'm sure someone must have claimed this theory!). This is where training is also imperative – to show the correct way of doing things.

But it also takes the people who notice the wrong, to immediately correct the situation (both, the thing and the person doing the thing), and hopefully the correcting is achieved in a positive way.

The bottom line – Training is an essential activity. (But I didn't need to say that, did I?)

6 OHW Interfaces

There are some important immediate interfaces that the Overhead Wiring system has to fit in with, and the following are what I consider to be some of the most important. They cover the substations and sectioning huts supplying the electrical power, the track, the trains themselves, civil interfaces, the signal system and the general surroundings.

The OHW design process for any new OHW usually requires a number of stages where an "All Parties Walkthrough" is performed on track in the area where the changes are proposed to take place. Everyone with a reasonable stake in the outcome should be invited to attend and give their informed opinions on the project thus far. This focuses on various interface issues as discussed below. All issues need to be worked through and agreed upon before progressing to the "Final Design" stage of the OHW design. The aim is to have *no surprises* for these people at the end when the OHW is finally built.

What follows is simply my understanding of these interfaces, but in some areas I might not be correct, and there may also be subsequent improvements that are not covered here. So, consult the Standards groups for a more accurate understanding (see *Section 1.2*, *Disclaimer*).

6.1 SUBSTATIONS & SECTIONING HUTS

Refer to *Figure 661*, which is a rudimentary (but admittedly busy) diagram showing some typical arrangement of how substations and sectioning huts feed the various OHW electrical sections. It includes the more fundamental equipment needed for this role, but there's a whole lot more complexity that cannot possibly be shown on this single diagram. But the focus here is on the *dc* side of things.

A *Substation* (S/S) provides the points of 1,500 volt supply to the OHW from the ac system. It has the necessary equipment to lower the voltage of the incoming 33kV / 66kV / 132kV ac voltage, and rectify the voltage to provide a nominal 1,500V dc supply for the trains. The transformer configurations normally give 12-pulse dc rectification. Large reactors (inductors) located within each substation help to smooth the resulting ripple current delivered to the trains to an acceptable level.

Special "high speed" 1,500V dc circuit breakers (DCCBs) are installed to offer quick isolation of supply to the OHW in case of a fault, or when the system operator requires the OHW to the de-energized (and possibly rail-connected by certain means), e.g. when there's the need to do "hands on" maintenance of the OHW.

A *Sectioning hut* (S/H) contains the DCCBs as for substations, but there is no ac supply injected into the system – they are fundamentally switching stations. So, they are cheaper to build.

Where possible, sectioning huts electrically parallel the various runs of OHW for all nearby tracks. This reduces *circuit resistance* and *energy losses* (I^2R) when supplying trains. It also improves the *voltage* to the trains (aiming to maintain above 1500V at the moving trains).

In doing this, sectioning huts allow the expensive substations to be spaced further apart, and this leads to a more economical outcome (if the energy demand allows for this).

The zones of dc electrical protection ("electrical sections") can also be made smaller by adding sectioning huts. This can help train operations in times when faults occur on or to the OHW system, resulting in less interruptions to surrounding train services.

Apparently, substations can be spaced up to about 15km apart in certain areas (on twin track with 2 intermediate sectioning huts ➔ Blue Mountains). However, the average distance is more like 9km with 1 intermediate sectioning hut. This distance is likely even less these days, due to the heavier electrical loads demanded by the trains.

It seems that the voltage at the substation can be as high as 1,700V, but normal operating range is typically 1,350V to 1,550V.

What follows are the 3 things I consider to be possibly the most important elements of substations and sectioning huts, that are essential to the reliable and effective operation of the OHW system, namely:

- ***DC circuit breakers*** (DCCBs) – for electrical protection,
- ***Isolating and rail connecting switches*** – for isolating supply to the OHW, and
- The ***Rail-earth contactor*** (REC) – for helping to deal with dc electrolysis currents whilst aiding electrical protection.

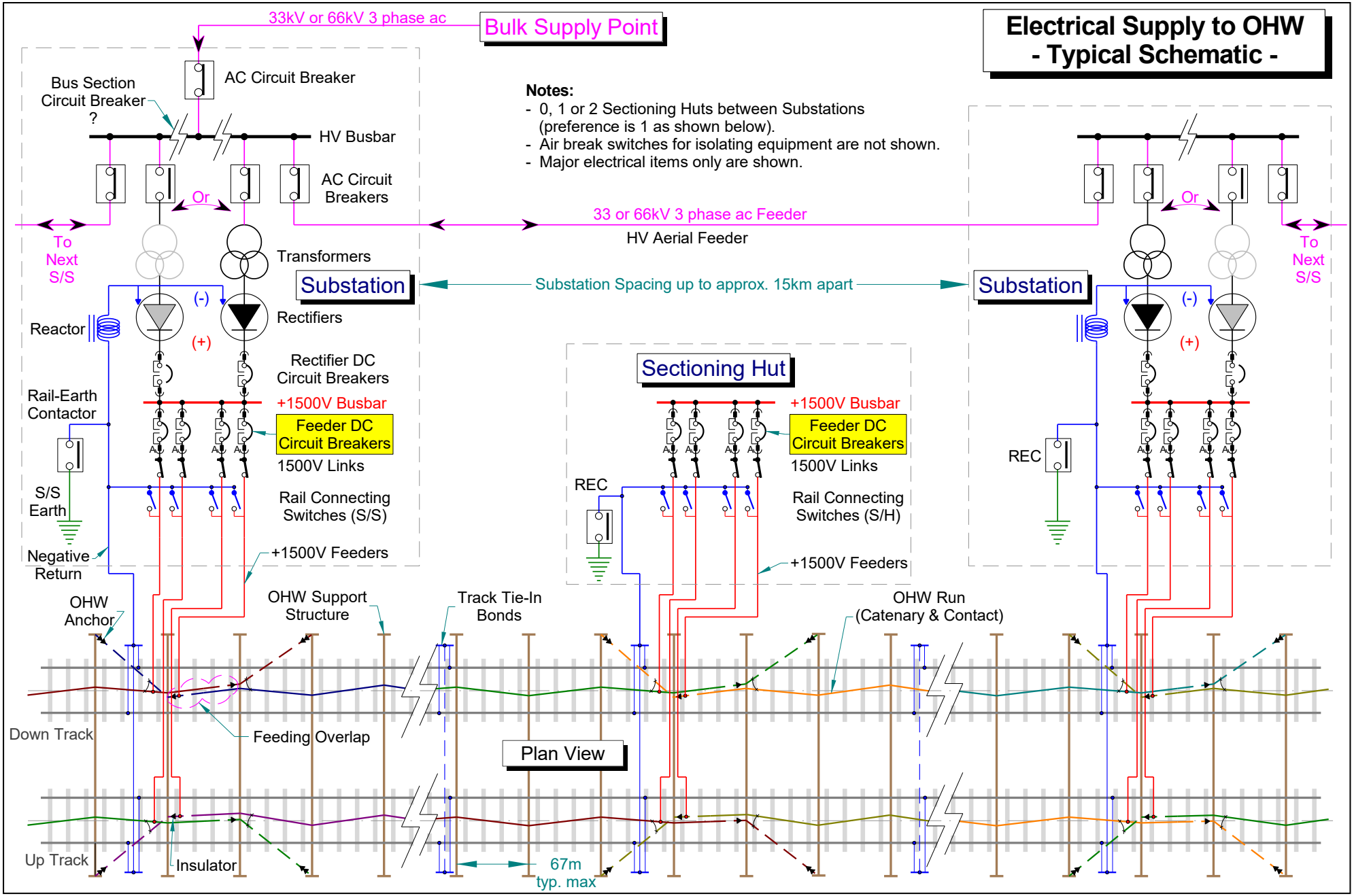


Figure 661 - Typical configuration of Substation & Sectioning Hut Power Supply to OHW (simplified)

6.1.1 High Speed DC Circuit Breakers

Of enormous importance to the OHW are the *high speed dc circuit breakers* (DCCBs) installed inside substations and sectioning huts. Their relative position in the substation and sectioning hut circuit is highlighted in yellow in *Figure 661*.

The DCCB is effectively a giant switch, albeit special in many ways. It stands about 1.5m tall and is typically mounted on a special 6-wheel "truck" to allow it to be withdrawn from its cubicle to be taken out of service and maintained. Refer to *Figure 662* for example.

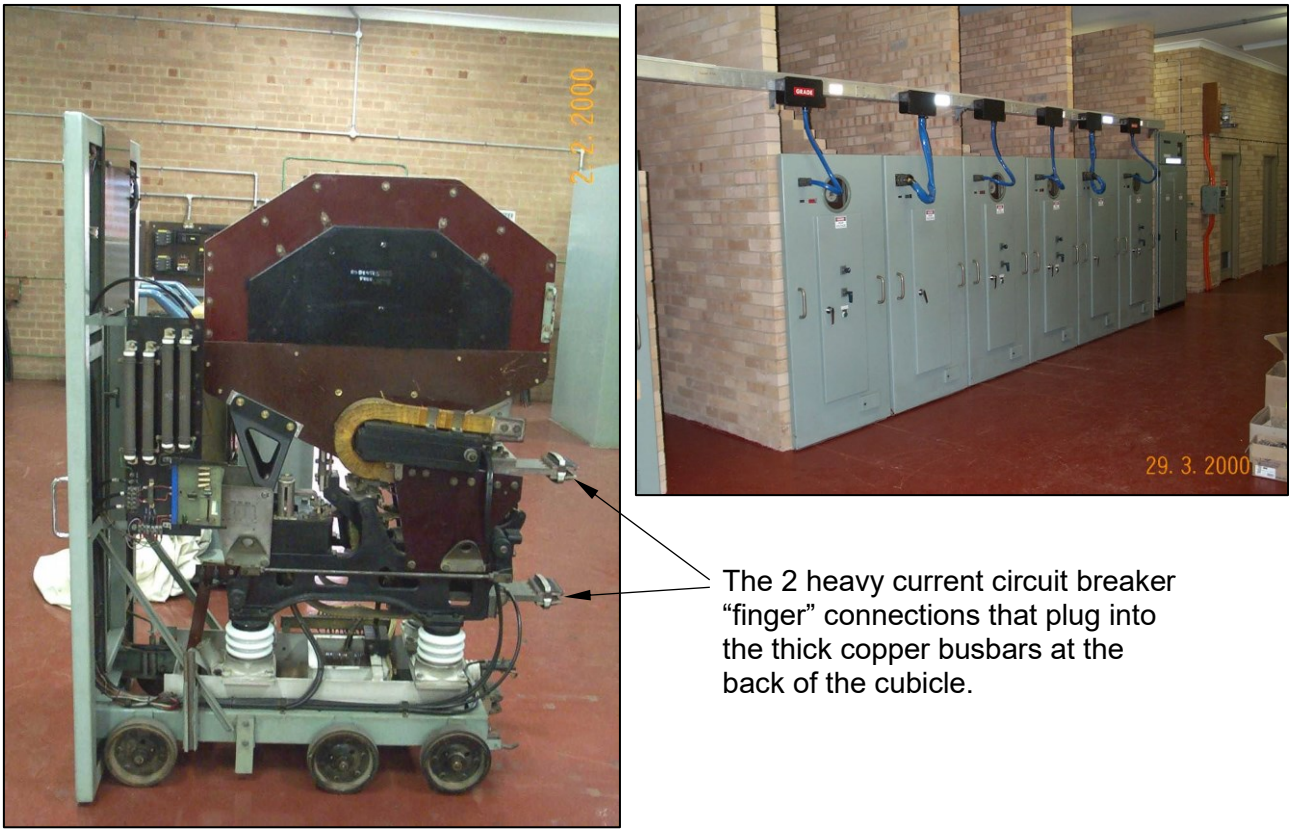

2. 2. 2000
29. 3. 2000
The 2 heavy current circuit breaker "finger" connections that plug into the thick copper busbars at the back of the cubicle.

Figure 662 - A Mitsubishi High Speed DC Circuit Breaker & Cubicles

One DCCB is installed at each point of feeding to the OHW. If an OHW section is fed by a substation at one end and a sectioning hut at the other end, each end will have a DCCB protecting that piece of OHW (which could consist of one or more continuous runs of OHW above a particular track). In this case, to isolate the OHW from 1500V, both DCCBs need to be opened.

DCCBs offer the necessary high speed protection to the OHW. They provide *over-current protection* by quickly isolating (tripping) fault currents set up to 6,000 amps or so, in about 20 or 30 milliseconds. The isolation must be rapid, otherwise 6,000 amps can do a huge amount of damage in a short time! (Energy ~ $I^2.t$).

I mention DCCBs here because, should they fail during a fault on the OHW system or train, the OHW conductors (catenary and contact wires) between the fault and the circuit breaker/s risk becoming overheated and annealed. This would permanently damage the conductors (i.e. rendered unserviceable) over long distances, sometimes of the order of kilometres. The damaged OHW conductors would likely then need to be renewed before any services could resume, which may take days to fix. (If you tried to retension the annealed conductors, they may just stretch until breaking point.)

Aside:

A while back I was told of an incident that happened a long time ago, where some old fixed-anchored OHW contact wire sagged on an extremely hot day and touched the roof of a train, but the DCCB protection did not operate (for whatever reason). Apparently, a passenger in the upper level witnessed a piece of molten metal drop from the ceiling and land near them! Relating this incident served to demonstrate the importance of effective and reliable electrical protection (but several things needed to go wrong for this to happen).

The big challenge for electrical protection engineers is to set the DCCBs so they can appropriately discern between:

- High level ***load currents*** – the DCCB's should remain *closed* (the train requires this to reliably operate), and
- Low level ***fault currents*** – the DCCB's must *open* (to quickly clear the fault and prevent damage and other problems).

Various calculations are needed to give the necessary confidence that the DCCBs are set appropriately to discriminate *load* versus *fault* in each situation.

To help in this regard, in addition to *over-current protection*, they can also trip on "rate-of-rise" – termed "Delta-I" protection. Here, if the current level begins to rise too quickly, this can be interpreted (by the current sensing electronics of the Delta-I relays) that there's a fault, and so it can trip the DCCB well before the high fault currents are ever reached. This predictive approach results on less stress being placed on the various heavy-current elements in the substation and OHW systems. (For more on Delta-I protection refer to *Section 5.7.3*.)

I'm not sure if the technology of "inter-tripping" is used yet on the 1500V dc side. On Sydney's traction system high voltage *ac* network, if a fault occurs on an aerial line feeding between substations, inter-tripping equipment (if installed in the substations) provides a communication link (via dedicated "pilot wires" running between substations) to help discern and deal with true faults. Simply put, if the sum of various currents, flowing from one substation to the next, do not add up, it implies there's a fault somewhere in between – on the HV aerial feeder. The communication link, transferring this information between substations (at close to the speed of light), then allows both relevant high voltage ac circuit breakers to quickly open and isolate the fault from both substations. In addition to the normal over-current protection, this adds another level of confidence that faults will be reliably detected and dealt with in the protection system. I know there was talk many years ago that this same approach may have merits on the dc system also (?).

Breaking a high-level *dc current* is a particularly onerous task, because it involves the rapid extinguishing of the significant arc that results when the circuit breaker is opened to isolate the circuit. DCCBs have various internal mechanisms that help to quickly and reliably achieve this, including magnetic blowout coils, specially designed arc chutes (to cool and extend the arc), etc.

I may be wrong, but I think these days the ratings of thyristors or similar discrete electronic devices may have almost reached a stage where they may be capable of replacing the bulky dc circuit breaker. (With these newer devices, I understand the huge electrical charge within the electronic device when conducting, needs to be quickly and totally swept away to achieve an open circuit, which is quite a tall order!) If successful, this would probably lead to a much smaller device than the existing circuit breakers, and being contactless, there should be much less maintenance. Maybe one day …

6.1.2 Isolating & Rail-Connecting Switches

Immediately beneath the Feeder DCCBs in *Figure 661* are the *1500V Links* and *Rail-Connecting Switches*.

The *1500V links* are simply heavy current switches that can be opened to isolate the 1500V supply from the substation to the relevant OHW electrical section being fed. They must not be opened whilst carrying any current, because they cannot always extinguish an arc and mostly are not designed for this. Instead, opening the links requires that the associated Feeder DCCB be opened first (which *can* deal with any current) – this removes the possibility of any current in the circuit, before the link is opened. Refer to the current operating instructions.

The *rail-connecting switch* provides a *quick* and *convenient* way of shorting out the OHW to rail. Although the 1500V links should exist in all situations, the rail-connecting switches may not. But the rail-connecting feature is becoming more essential these days because of the 2 significant benefits – quick and convenient.

To achieve the rail-connecting function, some situations have 2 inter-connected link switches. But more recent installations just use the single "ART (Multi-Contact)" rail-connect switch to achieve a similar outcome, as discussed in *Section 3.7.4*.

With the feeder having been confirmed "dead", the important thing is that the isolating switch is opened *before* the rail connection is applied (to avoid an extreme fault current that could otherwise result). This is why isolating/rail-connecting switch inter-linking is extremely desirable to bring about this outcome.

So, these switches provide the ability to keep the dc supply *isolated* from an electrical section (being fed), and to *rail-connect* that section. This helps ensure that any unintentional closing of the associated feeder DCCB cannot liven the feeder. They serve other functions as well.

In essence, they perform the same work as local isolating & rail-connecting switches positioned adjacent to the OHW. This is discussed in more detail in *Section 3.7.0.4*, *Rail-Connect Facility*.

6.1.3 Rail-Earth Contactor

The Rail-Earth Contactor (REC) is a vital piece of substation and sectioning hut equipment. *Figure 663* shows one such REC installation.

It's essentially a heavy duty switch device, with an electronic circuit that monitors the voltage between the Rail Bus and Earth Bus. (The term "contactor" implies the inclusion of a heavy current switch.)

In its normal "Open" state, it allows the substation or sectioning hut Negative Rail Bus (-1500V d.c.) to be isolated from substation or sectioning hut Earth Bus. This helps to force the train's current to return back to the substation *via the rails of one or more tracks* as intended, and not via earth.

However, if the voltage between Negative and Earth rises to 100V for 0.5 seconds, or 400V instantaneously (a.c. or d.c.) ± 20%, then the REC trips and closes its switch contacts – the "Closed" state – which then solidly connects the Negative Bus to Earth.

The contactor switch can also be operated manually.

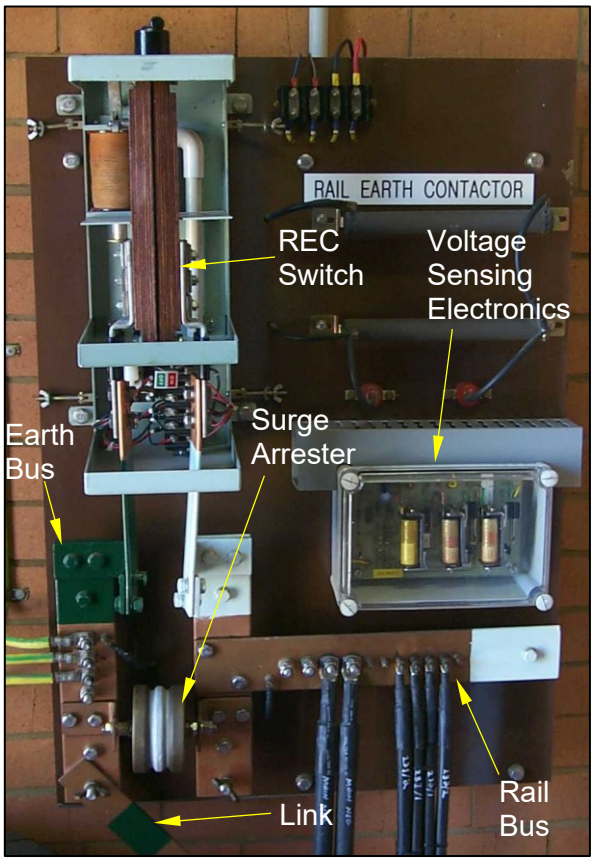


Figure 663 - Rail-Earth Contactor mounted on Substation wall

Closing the REC is done mostly for reasons of safety. In the case of a fault on the system, it helps to ensure a decent fault current passes, hopefully high enough to trip the associated DCCB and *isolate the fault*.

However, when the Negative Bus is tied to Earth, this can then also possibly cause additional electrolysis leakage currents to find their various ways back to substation, by other earthed paths in addition to the tracks (e.g. via pipe lines running near and somewhat parallel to the tracks, etc.). Unfortunately, this can promote more electrolysis corrosion along the path.

So, when the REC trips, supervisory indication is received at Electrical Operating Centre (Electrical System Control), who would then send substation staff out to find the fault and deal with it, with the aim of resetting the REC as soon as is practical, and thus minimise any further electrolysis currents and corrosion.

6.2 TRACK INTERFACE

An excellent guide to NSW rail terminology is document TMC 202, "*Track Fundamentals*".

The OHW exists because there's a track beneath it that electric trains travel along, and these trains need the electric power that the OHW, *and also the track*, will deliver.

The track position at any location directly affects the position of both the *train* and the relative position of the *OHW conductors* above the track for the train.

Referring to *Figure 664*, anywhere along its route, the design track position is defined in terms of its:

1. Lateral position,
2. Height ("Rail Level"), and
3. Superelevation (or "Super").

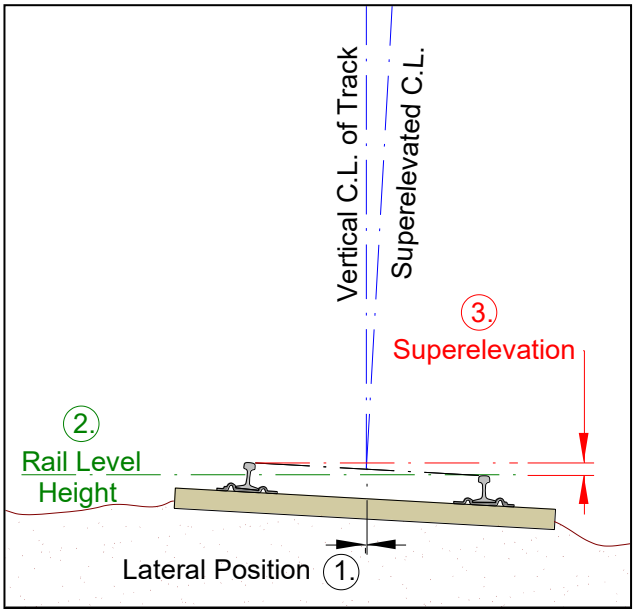


Figure 664 - Design Track Position

The track position therefore has a significant role to play in allowing the OHW to maintain *pantograph security*.

Considering the contact wire is some 5m above the track, any errors in any of these 3 elements can lead to a significant change (error) in contact stagger. Refer to *Figure 682* further on for a graphic showing the effect of the above 3 track position elements on OHW.

Various other standards exist which can provide further help in understanding the track and its positioning, including ESC 210, "Track Geometry & Stability".

I understand that the design of trackwork can be complicated. It's a 3-dimensional asset that needs to interface with adjacent trackwork and other elements (such as station platforms). So, it inherently involves the accurate *survey* of the existing track infrastructure and surroundings.

6.2.1 Track Terminology

What follows is a very *simplistic* description of various aspects of the track that can be somewhat relevant to the OHW infrastructure above it.

6.2.1.1 Track References

DOWN & UP TRACKS

This was partly covered in *Section 2.5.13*.

Most of the main line routes throughout the railways in NSW have pairs of tracks:

- One main line track to take trains *away from* Sydney (the "Down" track), and
- One main line track to take trains *towards* Sydney (the "Up" track).

Figure 665 shows a Down and an Up track (with back to Sydney).

The prime reference is Sydney's Central Station, so to remember the above convention it's useful to think of Central as being on the top of a hill – trains on tracks heading *down* hill are on the "Down" track, and those heading *up* the hill towards Central are on the "Up" track.

(Note that there used to be a complication at Newcastle which was also a reference, but as of December 2014 heavy-rail trains no longer go there.)

Aside:

Station platforms are numbered from *Up* track towards *Down* track. So, if only 2 tracks pass through a station, then Platform 1 would service the Up track and Platform 2 the Down track.

DOWN AND UP RAILS

The "Down" and "Up" reference can also be used to refer to individual rails of a track.

So, the "Down Rail" of a track is the left-hand rail when facing towards the country direction (with back to Sydney). The "Up Rail" is the right-hand rail of a track.

THE "4 FOOT"

This is a colloquial term used for the distance (or space) between the 2 rails of a track. This is the *track gauge*, and is actually the distance between the inside verticals of the rails of a track measured 15mm below the running surface.

In NSW the track gauge is **1,435mm** (4ft 8½in).

This gauge is referred to internationally as "standard gauge" (or "Stephenson gauge"), and is the same gauge used on high speed trains that travel in excess of 300km/h. (Australia has no such trains.) Apparently, of the 12 main gauges available, this is the most predominant gauge used throughout the world, and seems to be the preferred gauge for very high speed trains. About 61% of the lines in the world are constructed to this gauge (according to *Wikipedia,* *https://en.wikipedia.org/wiki/Track_gauge#Dominant_railway_gauges*).

THE "6 FOOT"

This is the colloquial term for the space between the Up and Down tracks – per *Figure 665*.

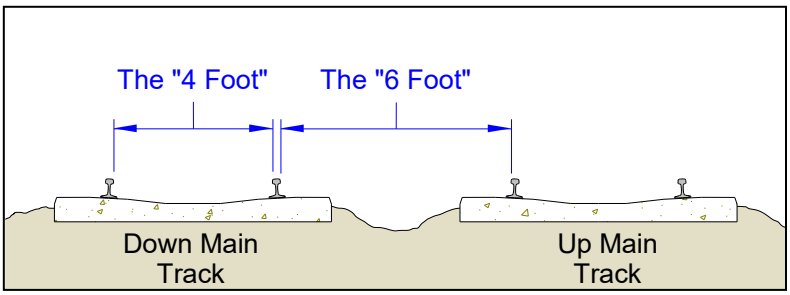


Figure 665 - The "4 Foot" & the "6 Foot"

Aside: The standard distance between the centrelines of the down and up track was 3.66m (12'), but this was increased to 4.0m in the 1980s (I think) to provide additional passing clearance between trains travelling in opposite directions.

6.2.1.2 Rail Sizes

Although there may be other older sizes, it seems in Sydney the most common *rail sizes* (densities) are those in *Figure 666*.

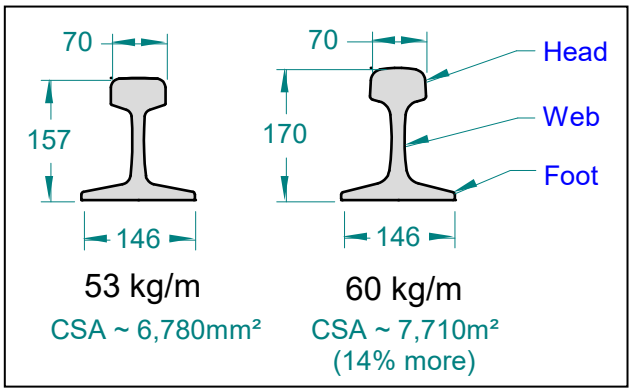


Figure 666 - Relative size of rail

53 KG/M RAIL

This was an old standard size of the steel rails used for track work.

60 KG/M RAIL

This is the current standard size of steel rails, which is thicker and taller than the 53kg/m rail.

There may be some older (smaller) sizes remaining in the electrified system, but I understand the above 2 sizes are by far predominant.

One real benefit of the newer 60kg/m rail to the electric traction system is that it offers a lower electrical resistance (R_{Rail}) because of its larger cross-sectional area. At a time when the power required to be delivered to trains by the dc system is at an all-time high, the larger dc return currents (I_{Return}) through the rails of a track are apparently causing the rail temperatures to increase (temperature is a function of I_{Return}^2 and R_{Rail}). Increased temperature lowers the tension in the rails (or apparently can put them into compression?).

So, the lower rail resistance will help combat this temperature rise, to a degree (so to speak).

6.2.1.3 Track Bed

My *simplistic* understanding is that there seem to be 2 main types of fixings of the track to ground – track installed on ballast, and track installed on a solid structure (with no ballast).

Track on Ballast

The majority of the track throughout the electrified network (and beyond) is regularly supported by sleepers laid on ballast (which is crushed rock often called "blue metal", and which is also used in substation yards). Apparently, the sleepers are spaced about 600mm apart for timber sleepers, and a fraction more for concrete sleepers.

The ballast formation raises the track somewhat, and provides excellent drainage and helps to ensure the tracks don't get submerged when heavy rain falls (unless there's nowhere for the water to go).

The main benefit is that it's relatively cheap to support the track this way. Unfortunately, it can allow the track to "move" in time to some degree, caused by the traffic load vibrating the track, and with the lateral loads as trains negotiate track curves, and with the changing tensile forces in the rails due to changes in rail temperature, etc.

Track on a Solid Structure

Here, the track is installed on sleepers or the like, with solid fixings to the structure beneath it. This includes installation onto a concrete slab or onto a steel bridge structure. The solid nature of the fixings to the structure prevents the track from any lateral or height movement.

This approach happens when it is desirable to lock the track in position so it cannot move, and often occurs in tight tunnels (due to the restricted lateral clearances for the train's operating envelope). It can also be used to lower the track and achieve greater vertical height clearances from track to tunnel ceiling, which can be useful at air space developments.

Track slab construction is extremely expensive, however it offers the big benefit of reduced

Figure 667 - Track rails held by "Cologne Eggs" on concrete structure

maintenance (e.g. no track adjustments and tamping required), and I guess it should result in more reliable train operations over the years.

With steel bridge structures, it makes sense to somehow lock the sleepers and installed track rails in place. This should add confidence that the track doesn't wander and cause subsequent problems with the OHW or other infrastructure elements, and is especially important if the track is well elevated above the surrounding ground, or passes over roadways, etc.

Increased transmission of "noise and vibration" are the likely adverse consequences of this system, and special rail supports can be installed to help minimise the train-generated vibrations into the concrete slab. These are installed individually under the track rails, e.g. "cologne eggs" (*Figure 667*).

6.2.1.4 Track Support

The 2 predominant candidates for supporting the track are shown in *Figure 668*.

Timber Sleepers

Old technology, but still in use.

Concrete Sleepers

Newer technology, with several advantages over timber. In particular, the heavier concrete sleepers are far more effective at keeping the track in place (not have it wander as much over time).

However, they are almost 100mm thicker than the timber sleepers, and this can lead to a reduced contact height if directly replacing wooden sleepers with concrete sleepers.

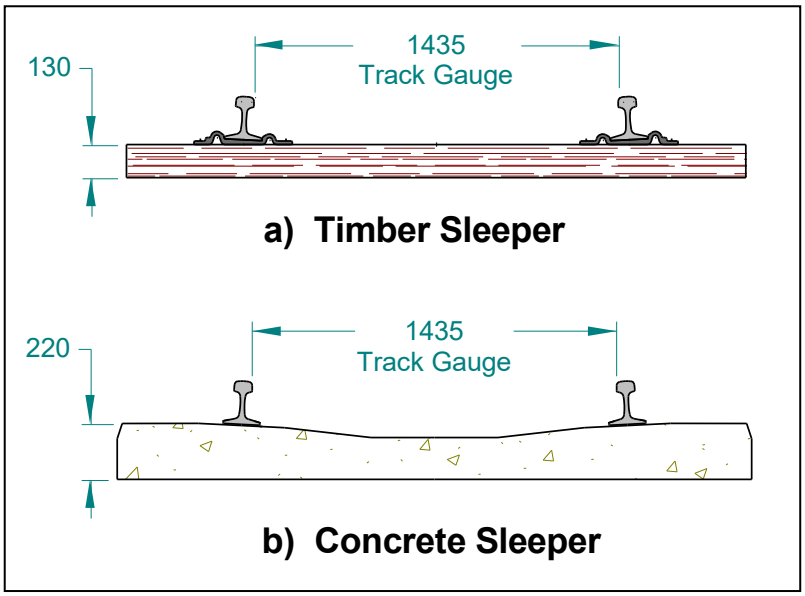


Figure 668 - Timber & concrete sleeper configurations

The "Metropolitan Track Strengthening" project was a huge initiative set up in the late 1980s to install concrete sleepers throughout the network to provide a more stable and reliable trackwork (especially beneficial under temperature extremes).

This project necessarily required the OHW to be checked out and adjusted, if necessary, to suit the higher track level due to the thicker concrete sleepers compared to timber.

At the time when concrete sleepers were installed, the opportunity was also taken to bring about some other beneficial changes, including providing the OHW with *Independent Registration*, which removed spans between tracks to improve train operational reliability by aiming to limit any OHW damage to the single affected track. This meant installing drop verticals where necessary for registering the OHW for remote track (in place of the cross-track span wire/s). Refer to *Section 5.6.1*.

6.2.1.5 Turnouts

A "turnout" is a configuration of track, shaped like a "Y" in plan view, that allows a train to travel in one of two directions. See *Figure 669*.

Typically, there is a normal direction and a reverse direction – the normal direction is usually straight through, while the reverse direction transitions out from this direction in a gentle manner to minimise passenger discomfort as the train alters direction.

A turnout can allow trains to access crossovers and sidings, etc.

A siding can use 1 turnout if it's a "dead end siding", or it can use 2 turnouts if the siding can bypass a section of main track, as in a "crossing loop".

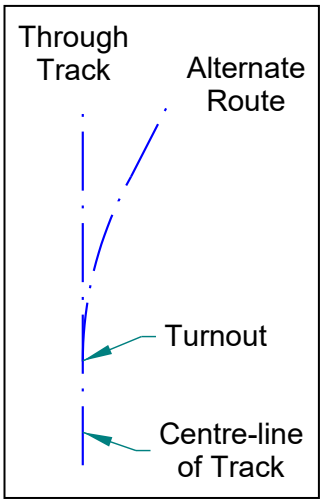


Figure 669 - A track turnout

6.2.1.6 Crossovers

"Crossovers" are short lengths of additional trackwork that allow trains to travel from one main track over to another.

They involve a "turnout" installed on each track, with a short length of track joining them. See *Figure 670*.

They can be configured as either a "Facing" or a "Trailing" crossover, and this depends on the main direction of train travel.

A "Diamond" crossover employs both these crossover types. According to TMC 202, "a diamond is formed when a crossover passes through a third track".

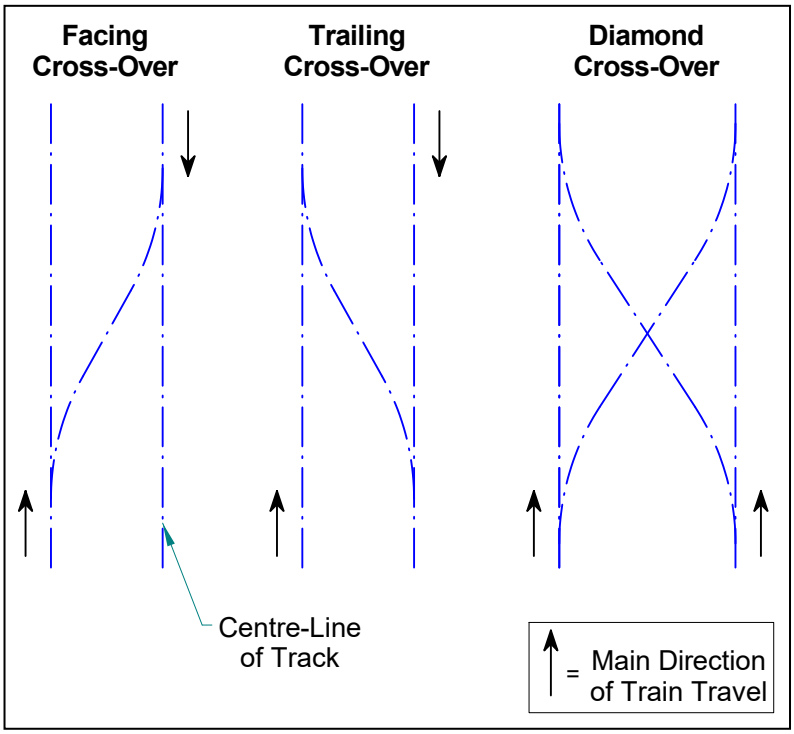


Figure 670 - Types of track crossovers

FACING CROSSOVER

A "facing crossover" is one that is configured to allow trains, in their normal running direction, to travel on one main track, through the crossover, to the adjacent main track.

This type of turnout is relatively easy to wire in a way that allows smooth pantograph transition from main line contact wire to crossover contact wire as the train enters the crossover. Likewise, for exiting the crossover.

TRAILING CROSSOVER

A "trailing crossover" is one where the train, in its normal running direction, cannot access the crossover, but instead would have to, if needed, reverse back into the crossover.

Unfortunately, the design of OHW to suit a trailing crossover is complicated by the fact that train pantographs travelling through the main line at speed can sometimes suddenly *strike* the crossover wire at the "forking-in point".

The ***forking-in point*** is the location where the edge of a pantograph can first touch a contact wire of an adjacent wire run in a turnout situation. It applies to trains on the main line track and also to those travelling on the crossover track, although they will be at different locations. (Refer to *Figure 611* further back). This striking can cause significant wear and eventual damage to the crossover contact wire (and possibly to the pantograph head). A *contact wear strip*, installed at this wear point, can help prevent further wear if this is the case, but such a sudden strike can also disturb the rest of the OHW conductors which can lead to poor pantograph performance in the area, including pantograph-to-contact arcing.

Refer to *Figure 671* which is part of an OHW layout for the Flyovers between Central and Redfern Stations. This shows several turnouts (both Facing & Trailing) and a Diamond Crossover. Note that all trains head in the *Up* direction here, which is towards the left. (All *Down* tracks are located beneath this Flyover structure, with the OHW on a separate drawing.)

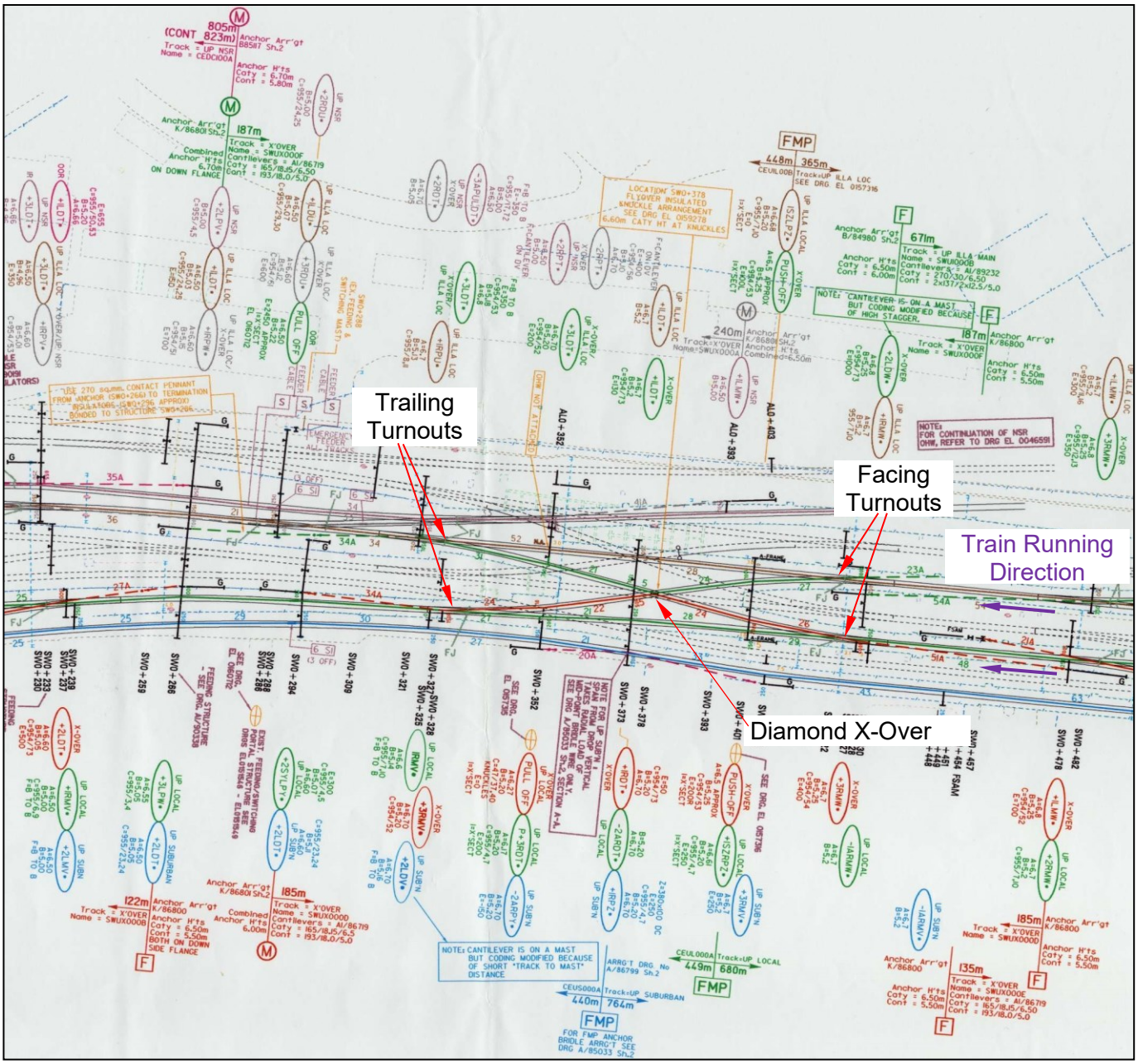


Figure 671 - Central Flyovers - part-OHW Layout showing diamond crossover

There's a vast number of crossovers located between the Down Main & Up Main tracks on all twin track lines located throughout the network. Trains may traverse the crossover to the adjacent track in order to then travel on this track, usually for short distances (in the opposite

direction) before reversing the train, or continuing onto another crossover (in a ladder crossover situation).

Section 5.1.29 has more details of the approach to designing OHW for servicing crossovers.

DIAMOND CROSSOVERS

Diamond crossovers occur where 2 tracks intersect at an oblique angle, shaped like an "X" (with no turnouts). Refer to *Figure 671* for instance. (Another diamond crossover exists beneath in the Flyunders for the Down track OHW, as shown with the dashed track linework.)

The OHW for this situation can be tricky – it involves 2 wire runs, and the contact wire should be at the same height in the vicinity of the crossing, providing a "flat" arrangement. The sharper the angle of a diamond crossover, the more the OHW needs to be a flat arrangement. (With much gentler angles it is possible to cross one contact wire over the other, per turnouts. There's no such luxury with sharper the angles here.)

This situation was shown previously in *Figure 118* in *Section 3.1.5*. Again, the design of OHW for turnouts is covered in *Section 5.1.29*.

Figure 672 - Trackwork with turnouts & recently-installed concrete sleepers (Waverton, 2012)

6.2.1.7 Rail Lengths

CONNECTION

These days, the serial connection of the discrete lengths of rail where they abut seems to be achieved using the "Continuous Welded Rail" (CWR) process, rather than relying on the older method of riveted links connecting them (or whatever term was used).

There are likely several benefits to the CWR approach, including a much smoother ride, less noise for passengers and people living nearby the rail corridor, less vibration into the supporting ballast (tending to destabilise it), etc.

But from an electrical perspective, the CWR connection must provide a far superior electrical connection, resulting in lower electrical resistance compared with the wire-linked connections (which I recall, relied on copper braids welded to each rail and spanning the butted rails).

TEMPERATURE CHANGE ISSUES

Unfortunately, the tension in the rails changes with temperature. Under cold conditions the rails contract, while under hot temperatures the rails expand, and the consequence can be a track that eventually moves around slightly if installed on ballast.

In order to maintain pantograph security, the track needs to be kept under fairly tight tolerances, both horizontally and vertically.

The effects, on the *contact stagger*, of a track moving horizontally are obvious. However, vertical movement of one rail relative to the other also has a significant impact on stagger, through altered track superelevation. See *Section 3.1.2* (and in particular *Figure 60*) for more information on this.

For instance, a change in *track superelevation* translates to a contact stagger change on the pantograph of *about 3.5 times this amount*. So, if the superelevation at a location is meant to be 0mm (on straight track) but is actually 25mm, this means the stagger at that location changes by 87mm, e.g. 250mm stagger becomes 337mm. This is a large amount (compared to the total limit of 381mm, including the effect of 130km/h wind blowout). And it's especially concerning when the effect of other tolerances on stagger need to also be taken into account at that location.

INSULATED RAIL JOINTS

"Insulated Rail Joints", needed for signalling purposes, require both rails of a track to be sectioned at a location, with a special thin insulating plate sandwiched between the cut and butted rails. Track-side impedance bonds connect to each side of the sectioned rail for both rails of the track.

This approach provides the necessary electrical continuity for passing the heavy dc currents demanded by trains, as well as isolating the ac waveforms used by the signalling circuit to detect a train on the tracks. Refer to *Section 6.2.1.15* for more.

6.2.1.8 Rail Levels

There are 2 levels associated with the position of the track, that are important to the design, construction and maintenance of the OHW. These are detailed below.

Refer to *Figure 673* for more of an idea of what these levels actually look like.

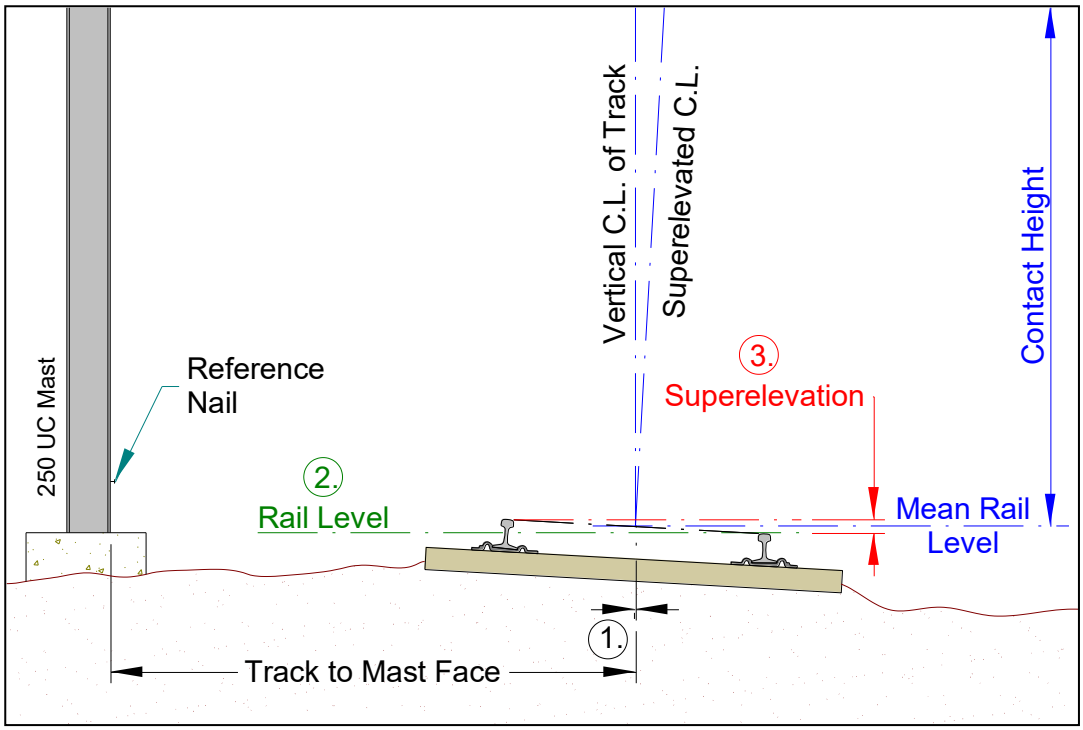


Figure 673 - Track position defined by 3 aspects

(LOW) RAIL LEVEL

"Rail Level" is the level of the *lower* of the 2 rails of a track at a particular location – seen as Item **2** in *Figure 673*.

The "Design Rail Level" is important when referencing the installation height of various OHW cantilevers attachment fittings on masts and portal structures.

The "Approved Rail Level" is the rail level that's accepted as the design rail level for a project, and is normally what the OHW is referenced to during its design and construction.

The vertical track alignment is used to determine the design rail level – *Section 6.2.1.10*.

MEAN RAIL LEVEL

"Mean Rail Level" is the average (mean) level of the 2 rails of a track at a particular location. This is equal to rail level *plus* half the track superelevation (which means that it doesn't matter if the track is on a left-hand or a right-hand curve).

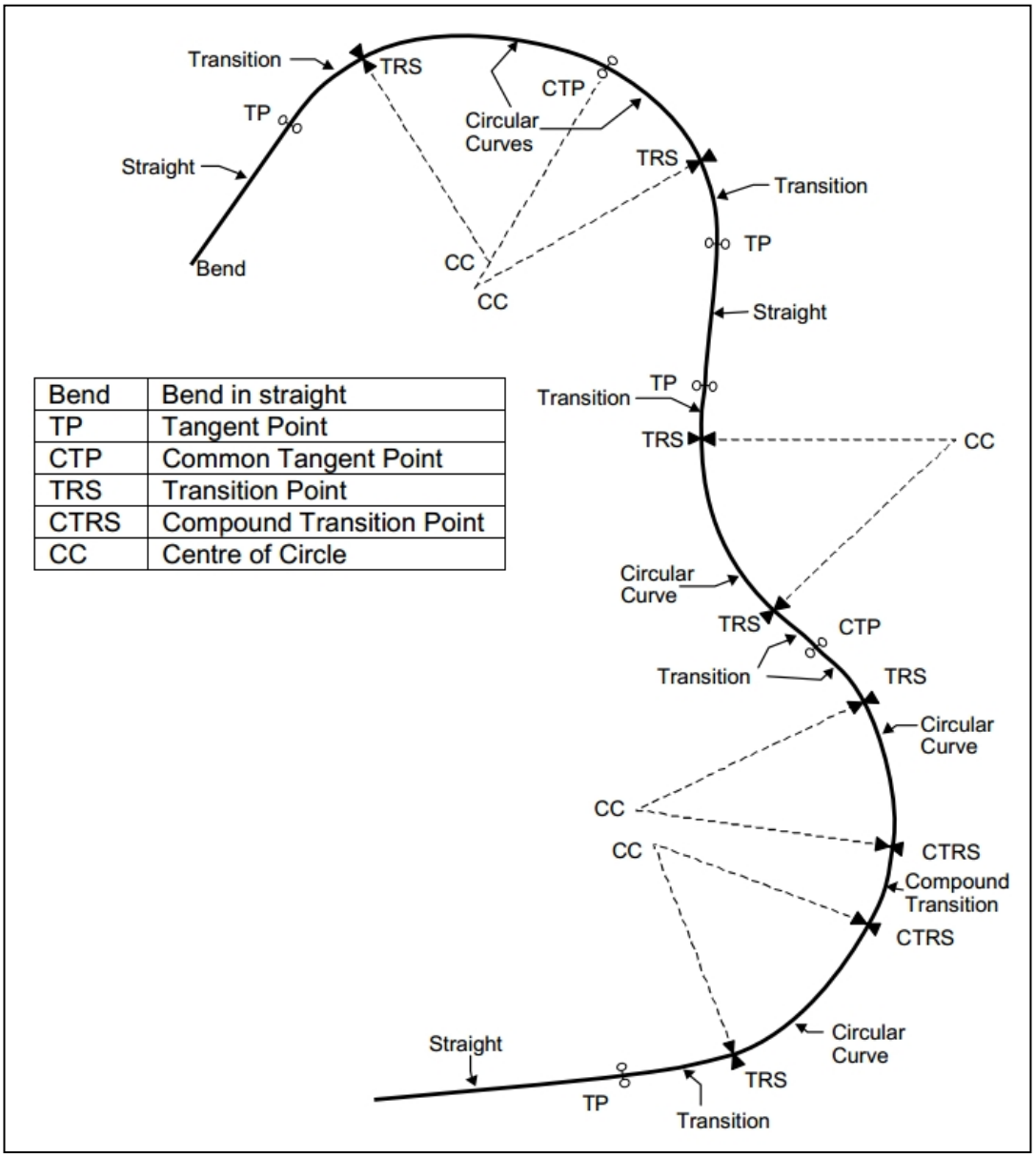
Its *design* position is important as both the *contact and catenary heights* are directly referenced above this level.

Unlike rail level, which is an actual point on a rail, mean rail level is located in space (half way between the 2 rails of a track), so it's a bit harder to actually measure in the field. Special height sticks include a flat portion that spans across and positions against both rail heads, in order to measure and record the contact and catenary heights at any given location.

6.2.1.9 Horizontal Alignment

OHW design relies on a *design track horizontal alignment* (the plan view). This is normally documented and signed-off as 1:500 scaled layouts. This information is developed by Track Design on CAD, and the CAD models form the basis of the OHW layouts.

The *design track horizontal alignment* is what dictates the position shown as Item **1** in *Figure 673*.



Bend	Bend in straight
TP	Tangent Point
CTP	Common Tangent Point
TRS	Transition Point
CTRS	Compound Transition Point
CC	Centre of Circle

Figure 674 - Horizontal Alignment Component Combinations (ESC 210)

Referring to Standard ESC 210, "Track Geometry & Stability", the track design defines the centreline of the "4 foot" of each track, which is composed of lengths of straight, curved, transitioned and compound transitioned track. The actual rails of the track are offset from the design centreline. I have included a capture of *Figure 1* from this standard, which helps explain the composition of a track design horizontal alignment – refer to *Figure 674*.

- A "straight" or "tangent track" is defined by a pair of tangent points (TP). A straight can be thought of as a curved track with infinite radius
- A "circular curve" is defined by 2 end points and the centre of the circle (defining a "track radius").
- A "transition" is the component that joins the straight to the circular curve, and is mathematically based on a cubic parabola. The transition is defined by 3 points – the tangent point (TP), transition point (TRS) and centre of circle (CC). Transitions, with accompanying *linear* superelevation changes, are important for the smooth transition from one track radius to another, which is particularly necessary for the comfort of passengers when travelling on a fast train.
- .A "compound transition" is the component that joins 2 circular curves of different radii. It is defined by 4 points – the 2 connecting points and the 2 circle centres.

The minimum track radius around a curve is about 200m on the main line, although there are instances in Sidings, etc. with radius down to 160m. Apparently, the current approach in Track Design is to design for no less than 400m where possible (?).

"Turnouts" occur where one track branches into 2 tracks. Most turnouts are deemed as "Low Speed", but there are a number of "High Speed" turnouts in the network, and these require special design with gentle transitions from main line over to the next track.

Figure 677 and *Figure 679* show typical ***OHW layouts*** (at Chatswood), including the track design symbology for defining the straights, curves and transitions in the track design.

6.2.1.10 Vertical Alignment

The track vertical alignment design (a side view) defines the design position of the *low rail* of each track. This is shown as Item **2** in *Figure 673*.

The vertical alignment is defined as a series of *constant grades* connected by *vertical transitions* into *vertical curves*, which I understand are mathematically based on a quadratic parabolas, and this helps improve the comfort of passengers at speed (among other things).

Curve & Gradient Diagrams can give details of the extent of track grades in the area, as shown in *Figure 675*. Far greater detail is kept by Track Design and the relevant District / Surveyors who are responsible for the maintenance of the track.

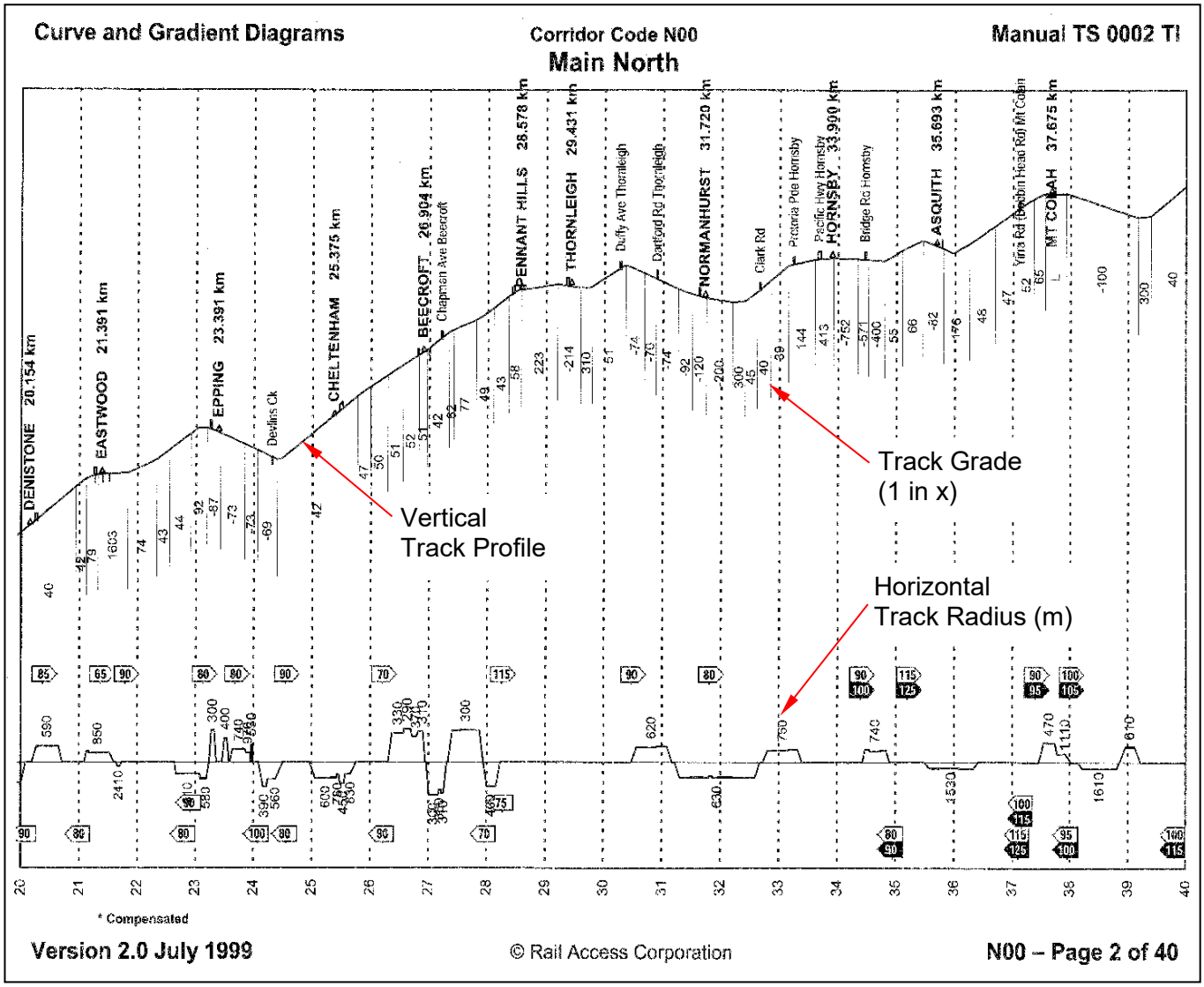


Figure 675 - Sample Curve & Gradient Diagram

Figure 678 shows an ***OHW profile*** view of the *track vertical alignment* and *OHW conductor profiles* leading into Nelson St overline bridge for the Down Shore track at Chatswood. (*Figure 677* was the corresponding OHW Layout for this area – Nelson St is near the right end.)

TRACK GRADE

This is the amount the track rises or lowers over a horizontal distance. A track grade of *1 in 81* for instance, is a slope of 1m vertically in 81m horizontally, or it can be expressed as a percentage – *1.23%* in this example.

I understand the maximum grade in the network is 3% (i.e. 3m vertical rise in 100m horizontal distance). Both the north and south approaches to the Sydney Harbour Bridge are apparently at or close to this 3% grade.

The basic track characteristics throughout NSW are given in publication TS 0002 TI, "Curve and Gradient Diagrams". This covers both the Electrified and Non-Electrified network. A sample is given in *Figure 675*.

6.2.1.11 Track Superelevation

"Track Superelevation" (or "Track Super" as it's commonly referred to) is the difference in elevation between the running faces (wheel contact points) of both rails of a track – see Item **3** in *Figure 673*. This design information is normally provided by Track Design.

The usual maximum amount of track super is about 125mm either to left or right (although I understand there are apparently some instances of super up to 140mm in the network).

Track super is often a compromise between the requirements for passenger trains versus freight trains. This is obviously due to the significant differences in train speeds whilst trying to maintain some sort of train lateral "equilibrium" and comfort around the bends.

6.2.1.12 Track Centres

"Track centres" is the horizontal distance *between* the vertical centrelines of 2 adjacent tracks at a particular location.

Where 2 or more parallel tracks are laid out together, their separation – track centres – should be sufficient to allow trains (often running in opposite directions and at speed) to pass without ever colliding.

Standard track centres on main electrified corridors used to be 3.66m, but many years ago this was increased to 4.00m to get a bit more passing clearance between fast trains travelling in opposite directions. (I'm guessing that this greater distance could be a matter of prudence to further reduce the risk of collision, or because of an increase in the train's *kinematic envelope*, or it could be so as to further reduce the amount of wind buffering that jolts each train as they pass at high speed – a comfort thing.) Kinematic envelope is discussed below in *Section 6.2.1.14*.

6.2.1.13 Catch Points

As stated in document TMC 202, "*Catch points are used to keep running lines clear of unwanted trains. They are a single* (track) *switch that can be opened to allow vehicle wheels to derail. They are often found where sidings are connected to running lines so that a train will derail at the catchpoint before it leaves the siding and fouls the main line.*"
They are a permanent installation.

This rather drastic measure is set in place at certain crucial locations throughout the network, to ensure that a much bigger train-on-train collision does not take place (if the culprit train should venture further along). It's a way of managing risks in difficult circumstances.

For the OHW system, the main point is that OHW masts or portal legs should *NOT* be located in the immediate path of catch points. If a train derails here, then ideally the train is less likely to affect any OHW infrastructure in the process of derailing (for obvious reasons).

A catch point happens to be in *Figure 672* – 3rd track from the left (in the centre of the photo).

There's probably a lot more to be said about catch points, but I will keep it simple here (it's getting out of my depth).

6.2.1.14 Kinematic Envelope

A "Kinematic Envelope" (KE) is the extreme outline (profile) of a rail vehicle in motion, which includes allowances for shift of the wheels on the rails, vehicle body roll and sway, vehicle centre and end throw, etc.

This outline is used by the track and civil design groups (and others?) to ensure that various infrastructure in the rail corridor cannot clash with the rolling stock. This includes station platforms and awnings, buildings built close to the line, tunnel clearances, etc.

Often an additional clearance amount is added to the profile to help ensure that these objects will never pose a clearance problem to the rolling stock. *Example:* KE + 200(mm).

Refer to the Track Standards for more details.

6.2.1.15 Track Tie-In Bonds

Special track-side "Tie-In Bonds" are installed by the signals discipline at frequent locations along the electrified routes. Refer to *Figure 676* for one such instance.

They connect to the rails of a track across "insulated rail joints" (where the rail is electrically sectioned), and also between tracks (where more than one track exists).

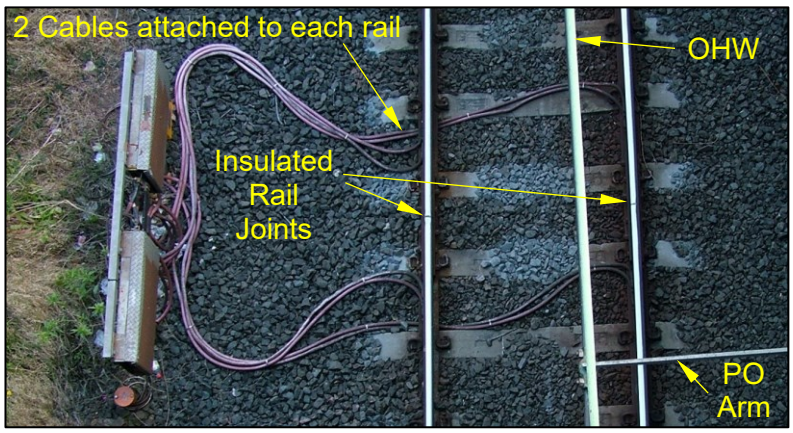


Figure 676 - Top view of track Tie-In Bonds for Signalling

These bonds allow the signalling system to identify the location of trains.

But also importantly, the rail pairs for 2 or more tracks in parallel can vastly reduce the track electrical *rail resistance* back to the substation, and thereby reduce the *voltage drop* to the travelling trains. This in turn helps to provide more consistent power for the trains to draw upon. For more, refer back to *Section 3.1.0.5*, *Energy to Train*.

So, these periodic tie-in bonds help to maintain a healthy 1500V supply at the trains themselves, as they move about the electrified system.

These bonds are shown back in the diagram of *Figure 661*.

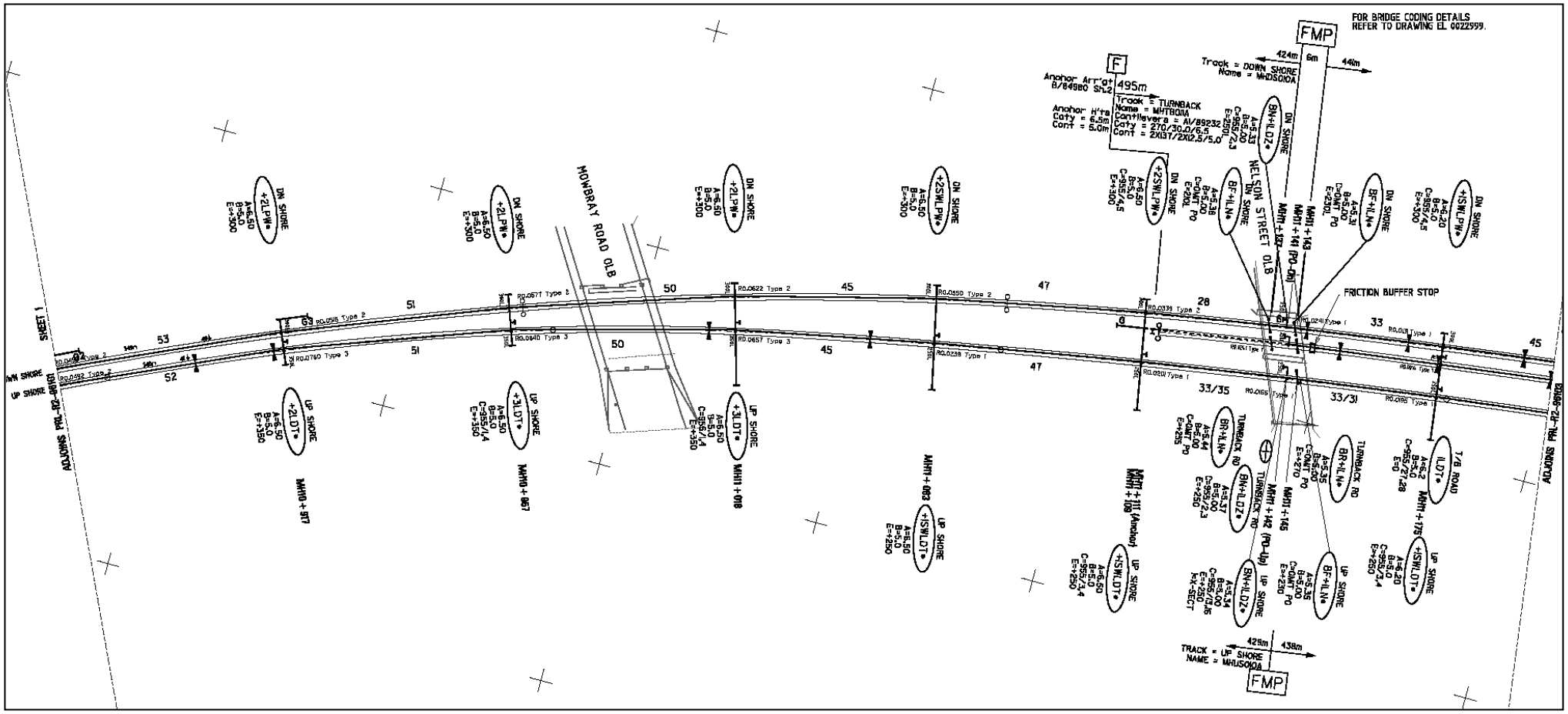


Figure 677 - Portion of OHW Layout showing track design Horizontal Alignment components (Chatswood)

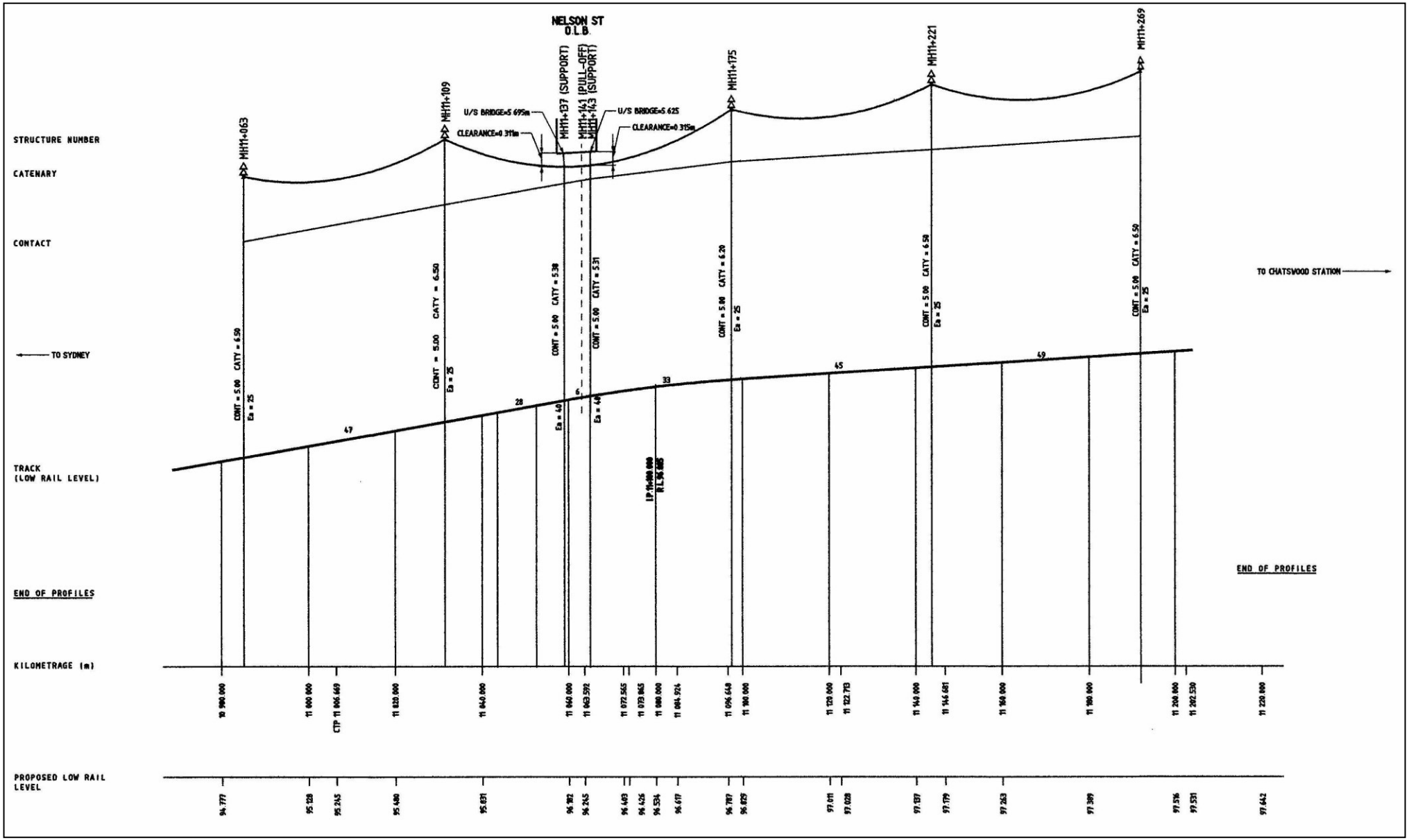


Figure 678 - Typical OHW Profile based on track design Vertical Alignment (Chatswood, Down Shore)

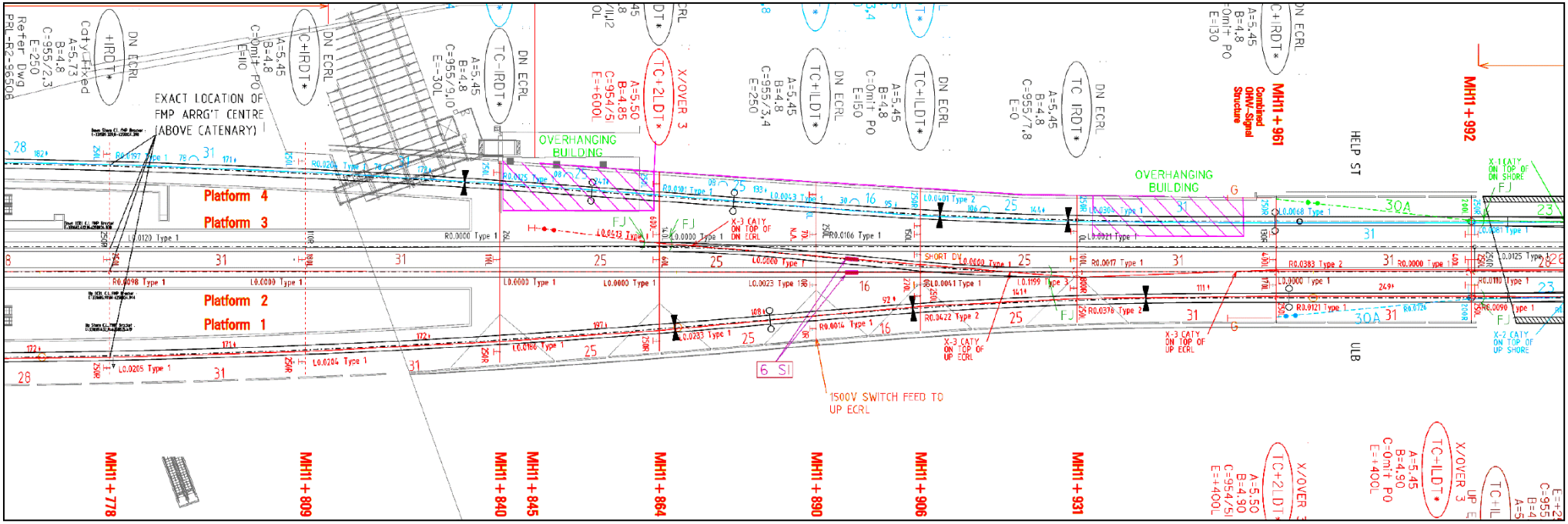


Figure 679 - Another portion of OHW Layout showing track design Horizontal Alignment components (Chatswood)

6.2.2 The Track Control Mark for OHW

The track has a "design" position and it needs to be maintained within tolerances of this position, otherwise among other things, pantograph security may be jeopardised.

The problem is that the track is a linear asset (rather than a discrete one), which makes it challenging to know its design spatial location every millimetre along its entire route.

To help manage this situation, surveyors install "Track Control Markers" (TCMs) at regular intervals adjacent to the track, most often installed on conveniently located OHW masts or portal legs. These markers specify the exact "design" location at these discrete points, and so they help staff to control the track's position. See *Section 6.2.2.1* below.

So, each OHW support structure has one or more TCMs installed that defines the design position of the adjacent track or tracks. The requirements of the TCM are documented in Civil Track standard TMC 212, "Survey". Also refer to ESC 210, "Track Geometry and Stability". See *Figure 673* further back – this shows the TCM marked as "reference nail".

The OHW support structures are used in this secondary role because they are a maintained asset that's robust, fixed in position and mostly located as close to the tracks as permitted. They are also frequently spaced apart (from 30m up to 67m) throughout the electrified network (which results in a huge population in the many thousands). TCMs can also be installed on other fixed objects, such as at platforms, signal structures, etc.

This is important because their distribution (TCMs on structures) can help maintainers know where the track *should* be (within tolerances), and this provides a huge benefit to the OHW and ultimately to pantograph security. (Or at least that's what was meant to happen.)

The TCM is installed by a surveyor, and a plaque is installed adjacent to the TCM to define certain track-related parameters. The height of the installed TCM is determined by the surveyor, but it's nominally about 300mm above rail level or 2,000mm in the case of installation on rock foundation or when the mast is located on a platform.

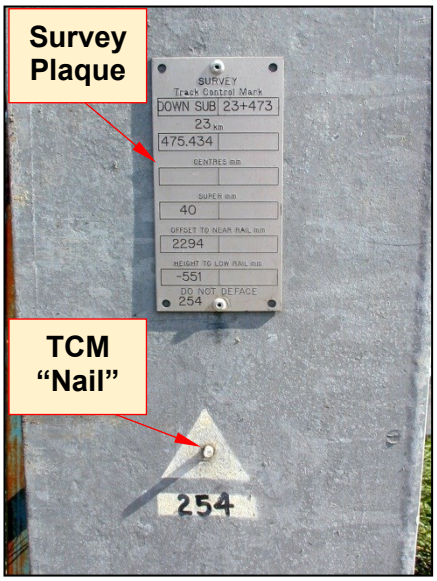


Figure 680 - TCM "Nail" & Plaque on an OHW Mast

The height of the TCM may vary significantly from these values, but this is of little consequence, unless the structure itself changes position or deflects when loaded with OHW (in a way that may alter any horizontal offsets to the nail).

Over the years, the TCM has also been referred to by OHW design and construction personnel as:

- A "Nail" or "Ramset Nail" (when installed in the flange of a steel mast), and
- A "Brass Bar" (when installed in a rock or concrete foundation when the OHW structure is installed at a higher level).

Refer to *Figure 680* and *Figure 681*.

I recall senior management in the Electrical Branch (as it was) celebrating the victory when it was mandated that TCMs be installed on all OHW structures. Prior to this, it was difficult to fault-find when a pantograph became tangled in the OHW, because the design position of track wasn't readily accessible. Was it the OHW, the train (pantograph) or the track to blame? The TCMs made subsequent investigations easier, as the track (as a potential culprit) could be ruled in or out relatively quickly.

6.2.2.1 Design Track Position

The design position of the track is defined by the following 3 aspects (refer to *Figure 681*):

1. ***Horizontal Offset*** – from TCM to design vertical centreline of track.
   (*Note:* the survey plaque shows design distance from TCM to the *closest running rail* of design track position, to which half the track gauge is added. After all, it's hard to measure to a half-way point that doesn't exist.)
2. ***Vertical Offset*** – from TCM to design Rail Level of the track.
   (*Note:* Rail Level is defined as the wheel interface level of the lowest of the 2 rails of the track. OHW heights are relative to Mean Rail Level.)
3. ***Track Superelevation*** – the design difference in levels of the 2 rails of a track (representing the incline of the track). Note that track superelevation is often documented as "E_a".

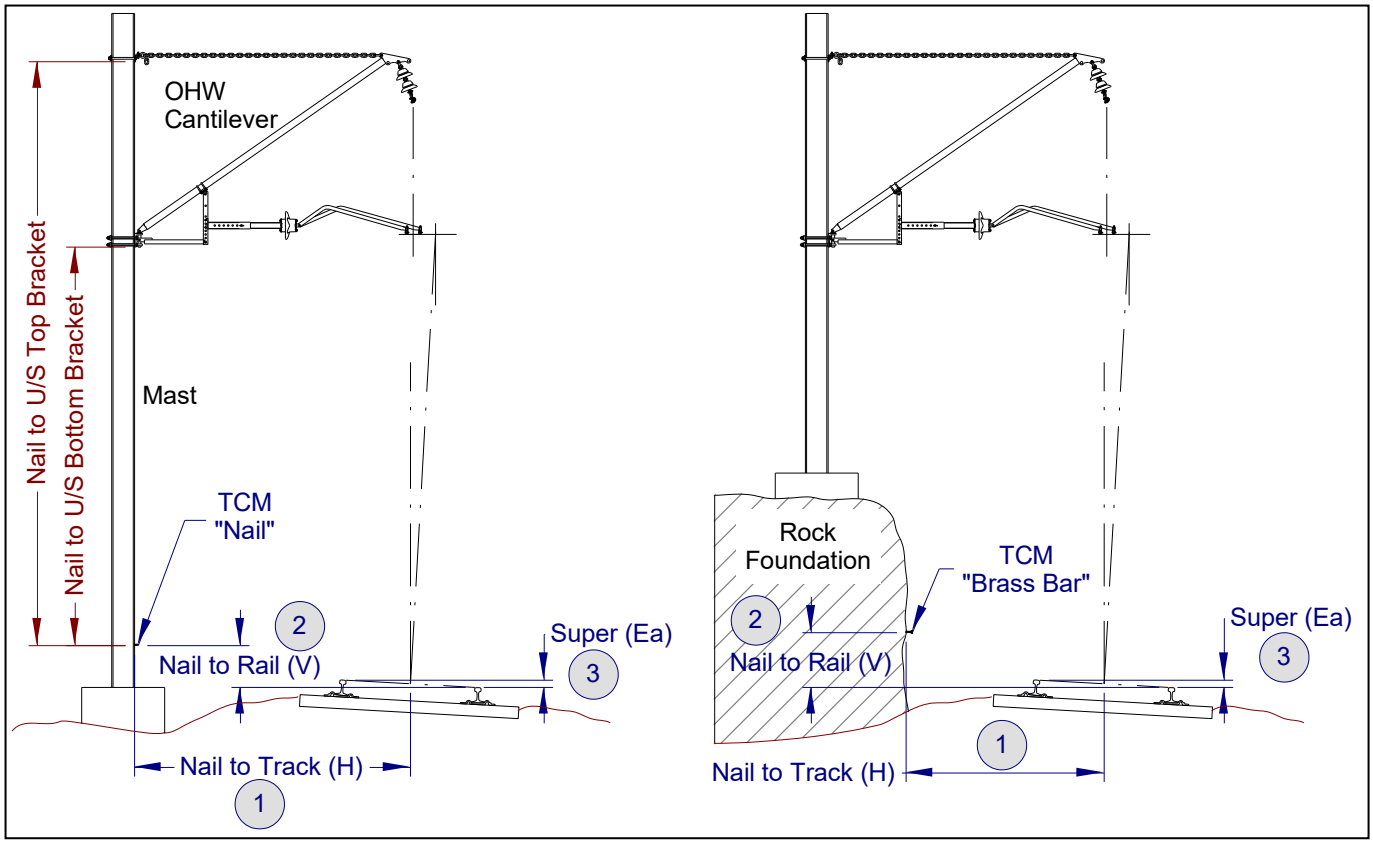


Figure 681 - TCM types on typical OHW Masts & track position aspects

All 3 aspects above need to be controlled within their respective maintenance tolerances, to ensure the integrity of the OHW to supply trains at speed (including *pantograph security*).

Typical track tolerance limits (relative to design track position) are given in ESC 210 for construction and maintenance. *Table 52* below shows allowable track tolerances applicable to the electrified network (unless notified otherwise).

Track Aspect	Track Tolerance Limit	Comments
Horizontal Alignment	±50mm	TCM to Track Centre (Horizontal).
Vertical Alignment: - Normal - Restricted Height Areas	 50mm higher / 100mm lower 25mm higher / 50mm lower	TCM to Rail Level (Vertical). In the Open Route In some tunnels and overline bridges.
Superelevation	±25mm	

(*Note:* Refer to ESC 210 for the most up-to-date details.)

Table 52 - Typical track tolerance limits for OHW

Refer to *Figure 682* to see the 3 types of track position errors (in **red**), and especially the effect on the all-important OHW *stagger*. The **blue** colour shows the design position, and the **green** colour shows the actual position at that particular location and time. (The tolerance errors on the drawing have been slightly exaggerated to help demonstrate the point.)

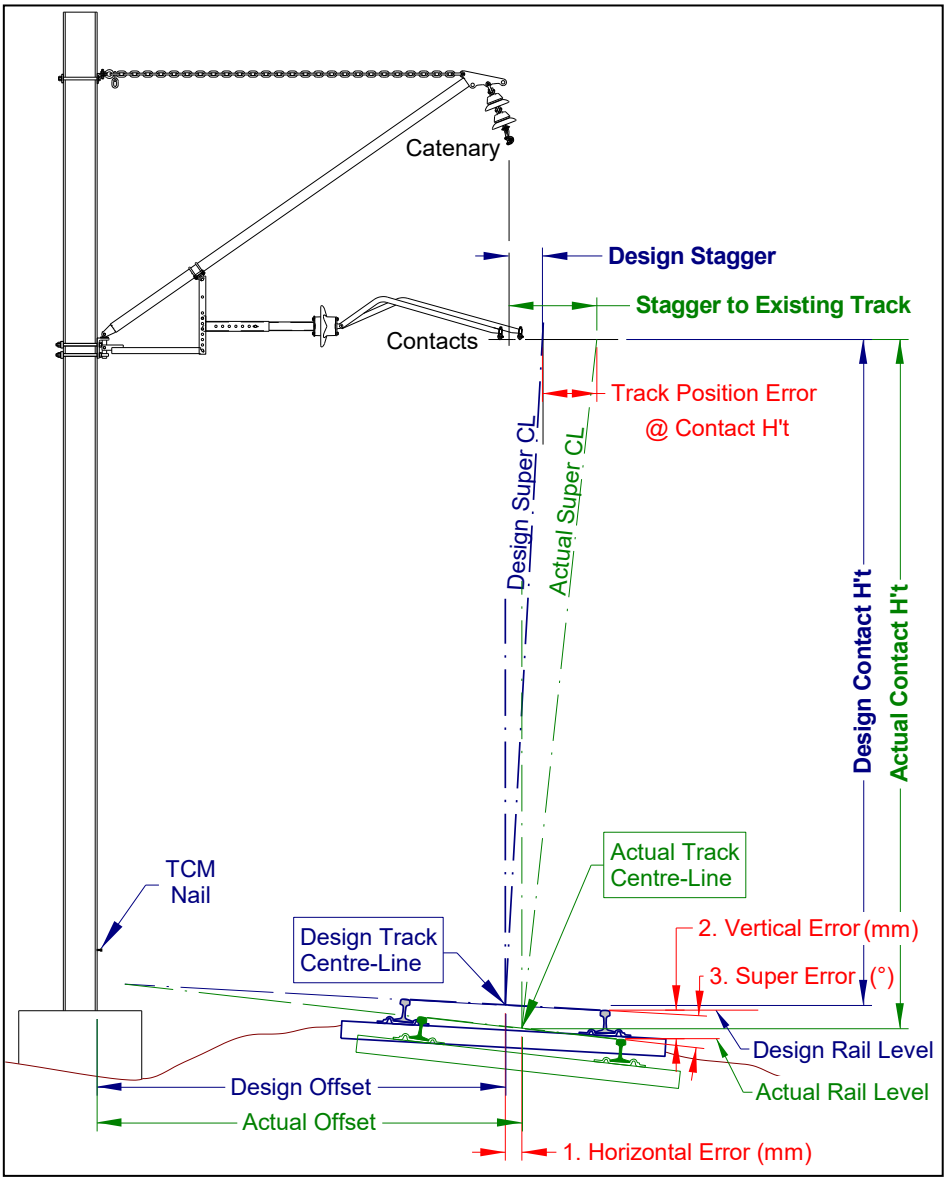


Figure 682 - Design versus Existing Track - Errors

As the diagram shows, the actual stagger can be quite different to the design stagger if the track is not well maintained in position, and this can have a huge adverse impact on pantograph security.

Errors in height are not such an issue out in the open, but they do become important inside tunnels and under overline bridges where the contact height is normally quite low already.

However, the combined effect of the errors that lead to *horizontal stagger error* can be quite large – the 50mm horizontal alignment and 25mm super error can translate to about 140mm stagger error if both tolerances are in the same direction. E.g. 300mm design stagger becomes 440mm actual stagger, which is absolutely *no good*.

6.2.2.2 Detail Design of Support & Registration

The construction details of the various standard OHW support & registration arrangements are mostly determined by computer programs such as "CCalc", "PO-Calc" and "T-Calc", and through site-specific cross-section drawings with their bill of materials.

These computer programs generate all the constructional details to allow the accurate installation of the variety of OHW cantilevers etc. on offer. The end result is the placement of the catenary and contact wires at a defined position above the track.

The contact wire is the most important component of the OHW support arrangements because it interfaces directly with a train's pantographs.

The contact stagger and its height above track are crucial to reliable train operations.

The accuracy of the above computer programs is such that, if the constructors set up all fittings relative to the TCM (and consequently relative to the design position of track), then they should be able to walk away from the cantilever with confidence that the contact wire will be in the correct spatial position, with the correct stagger and height within its tolerances, relative to the *design track* position.

The horizontal and vertical position of the contact wire relative to the TCM can be confirmed against the *CCalc Inspection Sheet* output, and these measurements can validate that the OHW is in the correct place, independent of the actual track position. This can form part of the documented evidence needed for the OHW construction quality assurance process. (Refer to this obligation in EP-08000015-SP, "OHW Construction & Commissioning".) These days there should be laser devices that can conveniently and accurately measure both horizontal and vertical offsets as required for this QA measurement. Note that the case of a Brass Bar installed in rock that's offset from the mast (the right-side case in *Figure 681*) requires a horizontal distance (offset) adjustment. Refer to *Section 5.2.5* for more details.

A final check should be done at the end of construction to confirm that the contact wires are acceptable relative to *existing track*, and only relatively minor adjustments may be necessary if the track is not in its correct design position. Tolerances play an important part here (see "Tolerances" below).

6.2.2.3 Tolerances for OHW

The engineering world works on tolerances, which can help reduce costs of unnecessary adjustments and ensure things work as intended. Hence, tolerances play an important part in determining whether any OHW adjustments are necessary.

The typical construction tolerances for the contact wire position are:

- Contact Height: ±50mm
- Contact Stagger: ±50mm.

(Reference: EP-08000001-SP, "OHW Standards for the Electrification of New Routes", Section 5.4).

So, if the contact wire stagger is within 50mm of its design value (relative to the ***design*** superelevated track position), then it should, in theory, be able to be left as is,
i.e. there should be no need to change the design stagger on the various design drawings.

But it seems that nothing in this world is ever straight forward and without complications.

Generally speaking, in the design process, if something is built *outside* tolerance then either:

- The designer, through calculations, deems that the situation is *NOT acceptable*.
  In this case, the OHW has to be reconfigured in the field to meet the original design (so as to be within its tolerance), or
- The designer, through calculations, has determined that the built situation can work and is therefore *acceptable*.
  In this case, the design should be altered to reflect the as-built situation. All affected drawings need to be corrected, e.g. change the original documented staggers (on layout drawings, etc.).

If it's found that the track is positioned outside its own tolerance (and causing the OHW to be outside its tolerance to the track), then this situation needs to be managed to correct it. Temporary adjustments can be made to the OHW (because it's usually quicker to adjust than the track), but eventually the track needs to be restored back to its design position, or else the OHW will need to be redesigned to suit the more long-term situation. When the track is finally brought back to being within its design position, the adjusted OHW will again require further adjustment back to its original design position.

The point here is that any track / OHW situation where one or other is not built within tolerance, needs to be effectively *managed* and not be forgotten over time.

6.2.2.4 Adverse Consequences

There is a tendency for OHW design and construction groups to build cantilevers to suit the *existing* track. This approach can lead to a significant waste in both time and cost, often with much fiddly adjustments needed to get the correct OHW contact wire position on these cantilevers.

OHW should be designed to the *design* track alignment, *unless* prior approval is given to design to the existing track position (wherever that may be on the day). Building the cantilevers relative to the TCM, and thus *design* track position should, in theory, avoid any such unnecessary adjustments.

According to the above track tolerance summary in *Table 52*, the OHW can generally tolerate a track that's built lower than its design level (by even more than 100mm in most cases). Conversion from timber sleepers to concrete sleepers is a classic example of how OHW can be designed for the standard 5m contact height to track on concrete sleepers, but can tolerate an interim lower track with the old timber sleepers and with a higher contact height of some 5.10m or so.

However, the 2 main operational threats arising from badly adjusted OHW are:

- ***Loss of pantograph security***. Incorrectly staggered OHW can lead to the pantograph failing to be adequately controlled by the contact wire throughout the bay, leading to the pan rising above the contact wire, with consequent damage to pantograph/s and to OHW equipment over a distance until the train stops. Refer way back to *Figure 29*.
- ***Low contact height***. Any track lift reduces the contact height, and a low contact height can sometimes result in this wire touching the roof of a train, causing the circuit breaker protection to operate and interrupting services. This is particularly relevant to fixed-anchored OHW, located inside tunnels or under overline bridges, under hot conditions. These are, by their very nature, notorious areas for "low wire" problems. But with a bit of care, even these can be managed and not pose an operational problem.

6.2.2.5 TCMs and the OHW Design Process

Having *Track Control Marks* (TCMs) installed and surveyed on masts and portal legs is essential for the correct installation of the OHW cantilevers. As far as I'm aware, this has been the case since about the late 1970s (but it could be earlier than this).

In terms of the OHW design process, the following approach used to apply for the situation when installing OHW cantilevers with insufficient mast information (e.g. mast not yet installed).

Unless requested by the Technical Reviewer, CCalcs were not required in design submissions prior to "Critical Design Review" (CDR) stage, e.g. at Concept Design (30%) stage. Refer to EPD 0013, Appendix "A".

"For Construction" CCalcs were to be submitted in the CDR Stage (100%), and be based on surveyed TCM positions. This means that OHW structures had been installed and surveyed.

In the majority of instances, OHW support structures can be installed well before the closedown used for placing the cantilevers on these structures. This allows the timely survey of structures and TCM locations for the needed offset distances in preparation for designing the CCalcs and other OHW hardware.

However, it is acknowledged that there will be times when a structure has to be stood and cantilever installed in the one weekend (provided the structure design and concrete set times allow for this). For example, if the track is to be slewed, but the mast cannot be installed prior because it would then be too close to the existing track. In these instances, it may be necessary to use temporary measurements (e.g. based on offsets from structural design drawings) for achieving "For Construction" CCalcs in a controlled way. But this situation needs to be properly managed, with follow-up CCalcs issued and any subsequent adjustments made, based on as-built survey.

The following cases of yet-to-be installed masts and portal legs are of particular interest:

Precast footing. For this case, the temporary height reference can be the top of concrete pedestal, and the horizontal reference can be the centre of the precast hold-down bolt group (giving centre of mast position), and adjusted to give the correct "Track to Mast Face" distance for input into the CCalc program. This will require survey to determine the level of top of pedestal relative to design Rail Level, as well as the horizontal offset from the hold-down bolt positions relative to design track position. Suitable temporary marking should be shown on the pedestal. Even the rake can be adjusted when the mast is finally placed on the pedestal, using packing pieces and/or hold down bolt level adjustment (nuts) to suit.

Planted post (PP). This will require the designer to come up with an agreed method of temporarily providing an alternative to the TCM. This process needs to be adequately controlled.

In each instance of all above cases, the method to be used was to be substantiated through a design report, including a risk assessment, and conveyed to the Design Checker and Reviewer. This approach was to be communicated to the construction manager for the work.

Also in the above cases, when the mast was finally installed, the TCM was to be established and the CCalcs, etc. rerun, based on the TCM and as-built structure position. This may require the already built cantilever arrangement to be adjusted, and its suitability for running trains reconfirmed.

6.3 TRAIN INTERFACE

The most important interface with the OHW is the train's several raised pantographs.

The pantograph belongs to the train and so is looked after by the Mechanical Section, which has always been *independent* of the Electrical Section in charge of the OHW. Therefore, any comments regarding the pantograph (and rolling stock) are based on ***my understanding only*** of their prime characteristics and behaviour (covered in a more generic sense).

6.3.1 Train Terminology

6.3.1.1 Pantographs

The pantograph is typically mounted within a dedicated "well" on the roof of an electric train.

It has a singular purpose – to collect electric current (at 1500 volts) through a sliding connection with the underside of the OHW contact wire/s, which then powers the train.

ELECTRIC PASSENGER TRAINS

These have 1 pantograph per car pair ("control trailer car" and "motor car"). The typical train configuration would consist of 4 cars (2 pantographs) and 8 cars (4 pantographs), and even 10 cars (5 pantographs) have operated on some interurban services.

Importantly for the pantograph/OHW dynamic interface, these pantographs are always spaced well apart – a good outcome when the train is travelling up to 130km/h or so (described later).

The pantograph spacing on a Tangara passenger train is indicated in *Figure 683*, (approx. 44.5m and 35m for an 8-car set), and a closer view of the pantograph is given in *Figure 684*.

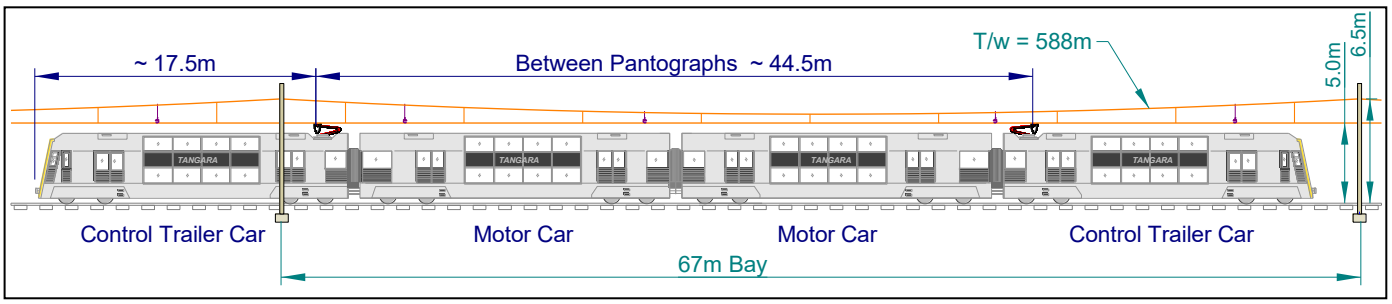


Figure 683 - Approximate distances between Pantographs on a Tangara train

ELECTRIC FREIGHT TRAINS

When they were operating, *electric freight trains* had 2 pantographs per locomotive. They could operate with ether 1 or both pantographs raised (depending on certain requirements).

Two, three or four locomotives could be coupled together at the front of the freight train, and this led to the possibility of up to 8 pantographs raised over a very short length of track. *Figure 498* further back is a photo of 3 × 46-Class locomotives hauling coal across the Blue Mountains (with 2nd, 3rd, 4th and 6th pantographs raised). And *Figure 524* shows an 86-Class locomotive with single pantograph raised, under contact-only OHW in Sydney Yard.

The pair of pantographs on a loco were each located approximately above the centre of the bogies. And the distance between the trailing pantograph on the front loco and the leading pantograph on the next loco gave an even closer spacing. I understand that for the 46 class loco these distances were approximately 9m and 7.5m respectively, and for 86-Class locomotives it was about 12m and 8.1m respectively.

This close pantograph spacing used to sometimes wreak havoc with any fixed-anchored OHW, especially when the contact tension was low (hot). The concentrated upward force of 4 or more pantographs, each exerting about 130N onto the contact wire and distributed over a relatively short distance, used to lift this wire by a large amount when its hot tension was only about 2kN! It's likely to be one big reason why the larger 193mm² contact wire was introduced in the 1950s, providing extra weight to help counter the concentrated upward force (See *Section 3.1.2.5*, *A Contact Wire with a Problem*, and *Section 4.1.2*, *Conductors*.)

A report on "Contact Wire Uplift" at Loftus was issued in 1987, on regulated single contact OHW (at 15.6kN tension). It physically analysed on track, the static uplift effect from a triple-header 46-Class locomotive configuration emulating all 6 pantographs raised, and was repeated for the spacings of a 86-Class locomotive. The report confirmed the large static contact wire uplift from these pantographs in their concentrated patterns (around 300mm at midbay and 150mm at catenary support locations at the ends of the bay). And this was on well-behaved regulated wire! Interestingly, the exercise was repeated nearby soon after under a long overline bridge having a series of 15m bays, and the maximum uplift diminished to only about 100mm mid-bay and 50mm at the ends of the bays for the 46-Class loco analysis.

From this report, and as expected, the inner set of pantographs caused the most uplift. And the closer the pantographs were grouped together, the greater the uplift.

The "Working of Electric Trains" (WET) book used to stipulate restrictions on the number and sequence of raised pantographs permitted on electric freight trains in certain parts of the network and under certain hot conditions (days). This was mentioned briefly back in *Section 5.1.5*, *Removal of Electric Freight Trains*.

Fortunately, the vast majority of Sydney's OHW network is now regulated (which can more effectively cope with this situation). But sadly, electric freight trains no longer operate.

Such pantographs under the current regulated twin contact OHW should perform really well.

6.3.1.2 Carriages

The carriages of a train consist of a ***chassis*** mounted on 2 ***bogies*** (one towards each end of the chassis). Each bogie consists of a rigid frame to which the various wheels are connected via a sprung suspension arrangement to help smooth the ride. The centre of the bogie is connected to the chassis by a special pivot that allows the bogie to rotate when the train travels around a horizontal track curve, and provides some connection flexibility as the train also deals with vertical track curves.

When traversing a horizontal track curve, the pivot location of the bogies relative to each end of a carriage, gives rise to an amount of "end throw". Additionally, the distance between the 2 bogies leads to an amount of "centre throw". These 2 offsets are dependent on the *track radius*, as shown somewhat exaggerated in Case **b)** in *Figure 684*. The throw figures of about ±120mm (1620 – 1500) are indicative of an exceptionally tight 200m radius track curve.

End-throw and *centre-throw* can affect lateral clearances to adjacent structures, such as station platforms located on curved track, and even to passing trains on an adjacent track. If the bogie pivot was located at the ends of the carriage there would be no end throw but a lot of centre throw, so I think the bogies are positioned to roughly equalise these 2 values for the best clearance outcome. For definition and equations on *end* and *centre throw* see Standard ESC-215, "Transit Space".

Aside:

> Any station platform located next to a track with a relatively tight horizontal curvature will require additional platform clearance to train, because of the resulting vehicle centre and end throw values. Unfortunately, because the track is located further away from platform, this then causes a greater *platform gap* for people to negotiate when boarding and alighting

from a train, which is always a concern. The train doors – like the pantograph – are located close to the bogie centres, which helps in this regard. And so, it would seem highly desirable to locate station platforms on straight track, to avoid the complications.

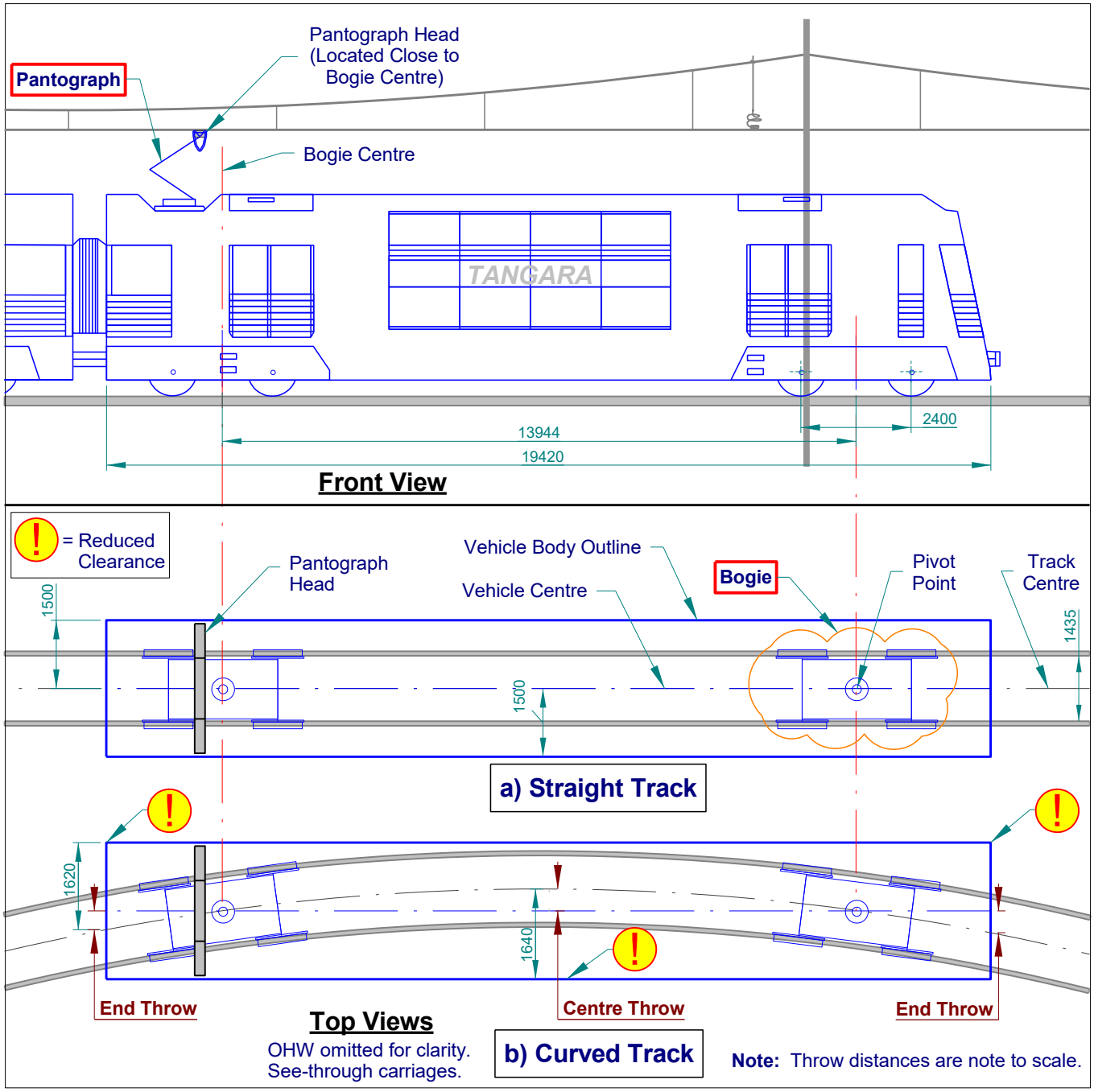


Figure 684 - Centre & End Throw and Pantograph location

6.3.2 Pantograph Aspects

Each electric train set has several pantographs on board to pick up power from the OHW.

The pantograph consists of a pivoting frame that is able to vary its height in sympathy with the height of the contact wire. In other words,

the Contact wire controls the Pantograph height.

Each pantograph exerts enough upward pressure (about 130N) to help ensure that a constant, arcless connection is made with the underside of contact wire, even at high train speeds. The upward pressure derives from air compressors located on-board the train. This upward

pressure should be fairly constant regardless of contact height, but can be affected by high train speeds caused by the aerodynamics of the pantograph arm and head.

The upward pressure must not be so great as to cause problems with the contact wire and OHW system. This can be a particular concern with fixed-anchored OHW at hot temperatures (with very slack contact wire tension), which can exhibit a large amount of uplift (> 300mm) near mid-bay. Refer back to *Section 3.2.0.5*, *Heel Height* for a bit more on this.

The evolution of pantographs, over almost 100 years of operation in Sydney, has seen a range of types for suburban, interurban and freight trains.

There are essentially 2 main styles (*Figure 685*):

- The older *scissor action*, and
- The more recent *single-arm* configuration.

It seems the lower mass, less wind resistance and other characteristics of the single-arm pantograph provide distinct advantages, in a way that help it to trace the contact wire profile and promote the ideal arcless connection with the OHW, especially at higher speeds.

Figure 685 - Scissor Action (top) & Single-Arm (bottom) Pantographs

At the top is the "pantograph head", which typically consists of 2 flat stainless steel carriers about 1.4m long, traversing laterally from one side of the train to the other. Specially shaped stainless steel "horns" are located at both ends of the head, and their downward taper is designed to help take up an adjacent contact wire as it comes into running from the side (e.g. at crossovers) without being snagged. The horns are intended to force the contact wire up and onto the top of the pantograph head. All good in theory.

"Carbon strips" (with graphite as a lubricant) are mounted into the carriers. I think older pantographs may have had four carbon strips, but more recent ones only have two. The top surface of these parallel pairs of carbon strips ultimately connects with the underside of the contact wire, providing a relatively frictionless connection, but able to pass heavy dc current (up to about 900Amps or so when moving). Although it likely varies across the different models, these days the cross-section of the carbon is about 35mm wide by 25mm tall, and the carriers are spaced about 300mm apart. Refer back to *Figure 392* for a close-up example.

The whole pantograph mechanism is supported on top of a train by 4 post type insulators (in parallel). These insulators provide the necessary 1500V electrical isolation to the train's metal body (and thus to rail), and they also give a strong and rigid connection of the live pantograph frame to the train. This later point is essential because of the various mechanical loads imposed from the interaction with OHW, and with wind loads and the general jolting action on the frame as the train travels along the track. Fortunately, post type insulators have immense strength and rigidity.

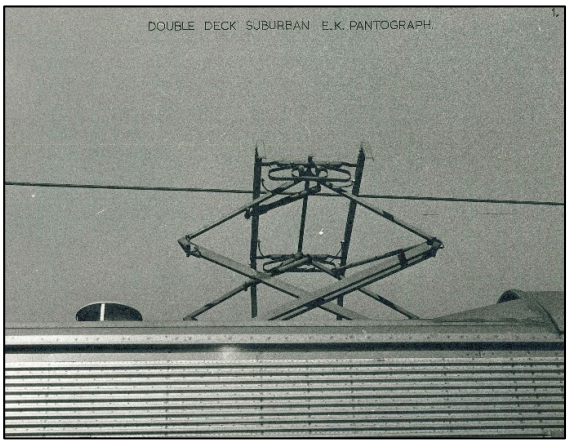


Figure 686 - Early style Pantograph

The pantograph should ideally be located *vertically in-line with the bogie pivot point*, so as to

not provide any additional lateral displacement effect relative to the contact wire when travelling on curved track. Otherwise, the effect is similar in nature to the "end throw" lateral offsets (on the vehicle body). Such effects would then need to be included in the calculation for pantograph security, and lead to an overall worse security outcome. Refer to *Figure 684*.

The pantograph should have low mass (inertia), to help it readily trace the contact profile without disconnecting from it (sometimes the contact profile is far from being perfectly flat).

Some *damping* on the pantograph is needed to help the carbon strips trace the contact profile throughout the train's journey. In particular, the dampers (like shock absorbers in a car) quickly calm down any dynamic vertical oscillations that may be set up in the contact wire by the uplifting travelling pantograph interacting with the OHW, or even by wind gusts. In an 8-car set with 4 pantographs raised, the leading pantograph usually creates little disturbance to the contact wire, but each successive pantograph passing through has to cope with that disturbance while generating its own additional disturbance for the next pantograph to cope with. So, the vertical movement of the contact wire can quickly compound in amplitude, with the last pantograph on the train receiving the brunt of activity. And this is partly why damping on each pantograph is so important – to quickly control such unwanted movement.

Apparently recent pantograph designs include a mechanism that causes the pantograph to lower (retract) if the carbon strips become worn below a certain thickness, thus preventing subsequent damage to the contact wire (and possibly other elements of the OHW system). This important innovation should ultimately improve service reliability and on-time running.

Sydney's electric passenger rolling stock consist of a *power car* + *trailer car*. The various train set combinations are based on this pairing, for 4-car, 6-car, 8-car and even 10-car sets.

In the modern fleet, it seems that a single pantograph is generally located towards the rear of each *control trailer car*, at the opposite end from the driver's cabin. Its paired *motor car* has no pantograph. These can be seen labelled in *Figure 683*. (The older fleet have different configurations to that described above.) Refer to RailCorp document RS00 0000 00MP, "Passenger Fleet Rolling Stock Diagram Book" for more details – an excellent summary.

As mentioned above, the purpose of a train's pantograph is to collect heavy 1500V dc traction currents to power the train, but it can also be called on to help slow the train down when required, through *regenerative braking* ("regen"), which feeds current back into the OHW.

Because of the power characteristics of Waratah trains recently introduced into Sydney's network, the train load currents are apparently now approaching the upper limits for a dc electric traction system – initially up to about 3,600 amps per train (but more recently limited to 3,200 amps). Spread amongst 4 pantographs, that's a massive 900 amps per pan = 450 amps per carbon strip (but fortunately only for short periods during *rapid acceleration*).

This places an enormous burden on the important pantograph/OHW interface – the contact wire must remain on the pantograph to provide smooth, arcless current collection at all train speeds and other defined conditions.

[I'm reasonably sure that, at one stage, the coupling of the pair of motor + trailer cars into 4 car units, with a pantograph at the opposite end to the driver's cabin, had the 2 pantographs connected (via power diodes?) to the common electrical supply for that 4-car train unit. And that this was done to help prevent intermittent loss of electrical power to the train should one pantograph momentarily disconnect. But I may be wrong here.]

Carbon strips were introduced onto the top edge of pantographs many decades ago to help extend the life of both the pantograph and contact wire, and this has been an enormous success for the OHW system. For example, I was told there are areas where the regulated twin contact wires on the Liverpool to Campbelltown to Glenlee (Macarthur) line are still the original wires installed in 1968 (some 50 years ago), and they're still in reasonable condition with acceptable contact thickness remaining. (Apparently, prior to carbon strips, special

trains equipped with a grease pot would regularly traverse the network lubricating the contact wire in an attempt to extend the [short] life of contact wire and pantograph collecting area.)

Before lowering a pantograph, the on-board circuit needs to be switched off so there is no chance of any current flowing as the pantograph is disconnected from the contact wire, otherwise there will be significant arcing which will cause damage and flashes of light.

Figure 687 shows some attempt to measure the uplift force on a pantograph installed on a freight train. This was done to help determine why there were significant pantograph/OHW dynamic oscillation problems experienced in the Gosford to Ourimbah area in the 1980s.

Figure 687 - Uplift force measured on freight train Pantograph at Gosford c. 1983

6.3.2.1 Pantograph Shape

STANDARD FLAT PANTOGRAPH HEAD

The top of the standard pantograph has a flat centre portion that spans laterally about 1.4m, and this area is mostly covered with a pair of carbon strips mounted on carriers – see *Figure 688* which shows various half-pantograph shapes. These carbon strips wear over time as they provide a sliding connection with the underside of the OHW contact wire.

At each end a stainless steel *horn* slopes diagonally down and away from the train. The horns are intended to connect with any adjacent contact wires coming in from the side, that may be lower in height than the top of pantograph at that moment (such as happens at turnouts). The adjacent contact wire is meant to rise *up* the slope of the horn which, in the process of takeover, may cause the pantograph to lower to its height.

However, if the contact wire goes *down* the horn instead, then it will eventually go past the bottom end of horn, rise up under the horn and begin dismantling the rest of the OHW system, beginning with the droppers, in-span feeders and pull-off arms! See *Figure 29* near the beginning of this document, for a graphical sequence of events (pardon my attempt).

As far as I'm aware, all pantographs (since the early days of electrification) have had a flat top profile in Sydney's electrified system. And the OHW has evolved to suit this shape.

Depending on the model, the pantograph head has a flat surface that extends anywhere from 1,200mm to 1,450mm, then drops down on a diagonal at each end.

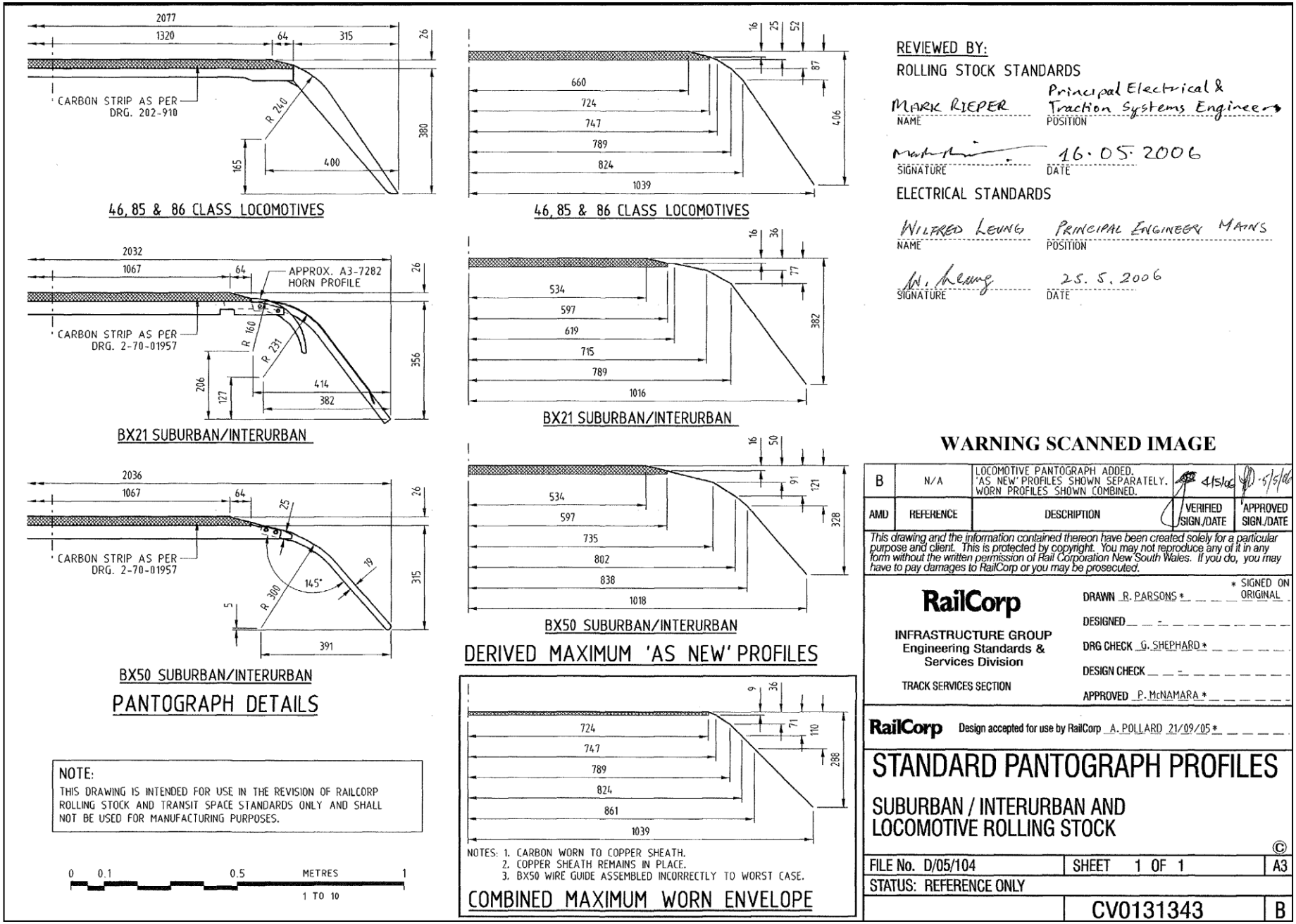


Figure 688 - Standard Pantograph Profile drawing

The current standard pantograph profile (for checking clearances to station awnings, etc.) is shown in drawing CV 0131343 in *Figure 688*. I understand the "Combined Maximum Worn Envelope" shape is a worst-case shape, taking into account the variety of existing shapes and brands. This drawing also shows the changes in extent of carbon strip coverage.

A PROPOSED "BOWED" PANTOGRAPH HEAD

Recent investigations had been conducted into the characteristics of a suggested "Bowed" (or curved) pantograph head shape. Refer to *Figure 689*. The consequent report was titled "New 'Bowed' Pantograph – OHW Interface Aspects", dated 2/2/2011. This report includes the following conclusions.

> *The fundamental "Bow" shape should provide benefits to the OHW system, especially with trains travelling at speed when approaching crossovers and turnouts. In this situation the contact wire from an adjacent wire run comes quickly into running onto the pantograph from the side. The bowed shape should allow this take-up without causing any side wear to the contact wire (which is a current problem). The bow shape is popular overseas, this possibly being one of the reasons.*

However, in the report the main concern with the bowed shape was how it interfaced with the section insulators, and in particular the Type 6 SI (Jacques Galland), and mainly because of the widely spaced side runners of this SI (spaced 410mm apart). *Figure 689* is a longitudinal view of the suggested pantograph shape, and with the Type 6 SI superimposed.

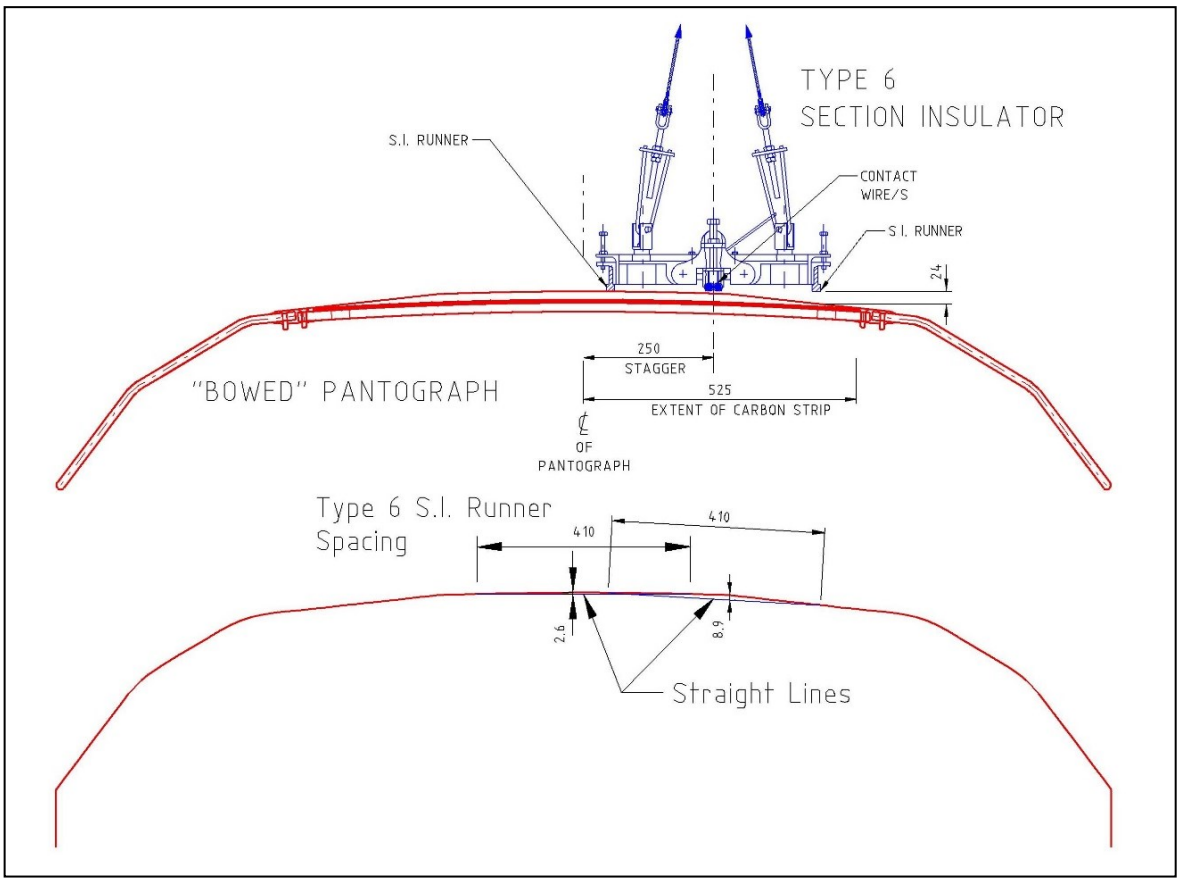


Figure 689 - A trial Bowed Pantograph with Type 6 SI staggered at 250mm.

At an across-the-table meeting with the French SI manufacturer, they had confirmed that a bowed shape may cause problems. They advised that the side runners could be adjusted (lowered) to suit a bowed pan, however the *pan curvature*:

- Must be a *constant radius* over the effective current collection zone, and that

- All of Sydney's pantographs would be required to have this *same shape*, i.e. you cannot mix both flat and curved pan shapes without some eventual reliability problems occurring.

The problem is that the Type 6 SI has both side runners levelled so that they are on the same flat plane as the contact wire coming into and heading away from the SI. When the bowed pan approaches the SI, its arc radius causes the pan to run on the contact wire and without contacting *both* side runners. When the pan gets to the gap at end of the contact wire termination, the leading carbon strip can then rise into the gap between the sectioned contact wires – only then is the pan height controlled by both of the side runners. As it advances, it will likely *strike* the abrupt flat end face of the next contact wire – refer to *Figure 690* for a side view of what happens in this crucial area. The amount of pan rise in this notched area is 2.6mm if the SI is at zero stagger, but a much more intolerable 8.9mm if the SI is staggered 250mm (in either direction) at that location. These figures are shown in *Figure 689*. Although these small vertical distances seem trivial, at medium to high pantograph speeds the abrupt strike will most likely damage the carbon strips and affect operational reliability.

Sydney has a huge population of Type 6 SIs, and they have proven to be quite successful over the past 4 decades. If the bowed shape were to be incorporated, all these Type 6 SIs would likely need to be replaced. Or they could be adjusted as suggested by the manufacturer, but then *all* pantographs would need to be this shape (no more flat pantograph heads).

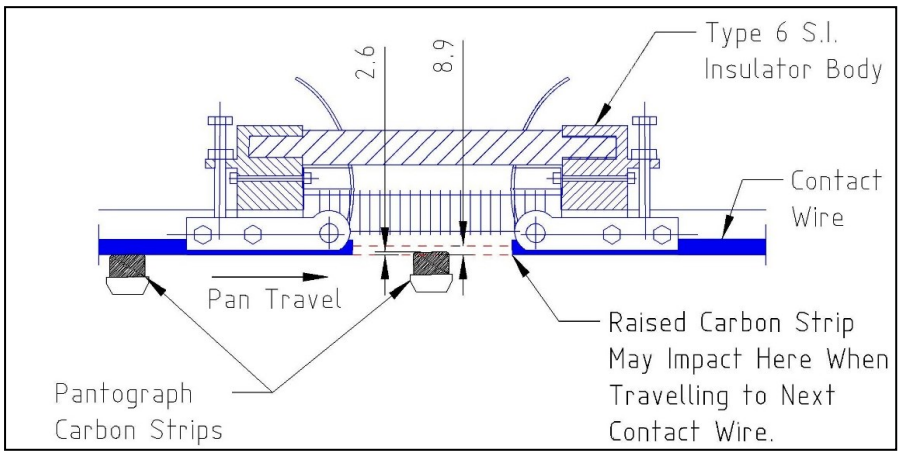


Figure 690 - Longitudinal section showing gap between terminated Contacts causing "Bowed" Pantograph impact

Some form of "bowed" pantograph ***is a good idea***, as it can help interface with the OHW in a number of ways. However, because of the *abrupt strike* problem mentioned above, in the report it was recommended that this particular bowed pantograph shape not be used within Sydney's electrified system, until such time as the various uncertainties are properly evaluated and dealt with. Otherwise the system reliability may suffer.

I understand trials are still taking place in a hope that this or some other new shape will somehow be endorsed. But the implementation of such will need to be properly managed.

6.3.2.2 Pantograph Security

The pantograph must always remain under the OHW in-running contact wire, and have its height controlled by this wire. This is regardless of track shifts and superelevation errors, train speed, train bogie sideways movement and vehicle sway, OHW construction tolerances, 130km/h cross winds, etc, which are all major aspects that can affect the OHW and its position relative to the pantograph in the imperfect real world.

This fundamental requirement is termed ***Pantograph Security***.

If certain aspects are not properly controlled, then it becomes possible for the contact wire to venture too close to the outer edge of the pantograph, resulting in the likely consequence that the contact wire no longer controls the pantograph (with its large upward pressure). In this scenario, the uncontrolled pantograph may then rise above the contact wire, whence the OHW system gets ripped down by that pantograph. (Refer to *Figure 29* near the beginning of this

document for the possible sequence of events.) In doing so, vulnerable OHW equipment (droppers, in-span feeders, pull-off arms, etc.) can become damaged for quite a distance until the train comes to rest and/or the pantograph gets demolished. This can affect all pantographs on the train. *Figure 697* a bit further on shows one such damaged pantograph.

Section 10.3, Appendix "C" – Pantograph Security contains the established guidelines (within Sydney's traction system) for ensuring Pantograph Security. It is a document that's crucial to the reliable operation of Sydney's trains. I understand it was based on a rail industry presentation given by a previous Electrical Supervising Engineer, F.C.P. (Phil) Smythe, entitled "Overhead Wiring Design for Pantograph Security". The original document gives an idea of the accepted allocation of portions (or budgeting) for the 3 interfacing systems:

- ***OHW contact wire lateral movement*** (caused by stagger, blowout, construction tolerances, mast deflection due to wind, etc.).
- ***Pantograph lateral movement*** (caused by bogie movements and vehicle sway, etc.).
- ***Track movement*** (in terms of track tolerances on 3 aspects: *lateral* shift, *height* shift and *lateral effect of track superelevation* at the contact wire height).

If the aspects identified in the above document are kept within their limits, then the security of the pantograph can be assured.

The OHW design process intends to keep the contact wire (when *in-running*) within 381mm (15") of the centre of pantograph, even under 130km/h wind conditions. This is a fairly old requirement that has never been challenged (to my knowledge), and the resulting reliability of OHW / train interface is testament to its effectiveness. Refer to *Figure 692* for 2 cases – on *straight track* and on *curved track* – where the staggered contact wire needs to be maintained within the ±381mm band (either side of track centreline), even with a strong wind blowing.

On curved track with the track inclined, the centreline of the pantograph is ideally on the superelevated track centreline, so the ±381mm limit is also related with this line.

The difference between this 381mm figure and the end of the carbon strip of the original pantograph, is a distance of 343mm, and this distance is deliberately allocated to all sorts of other tolerances mentioned above. This 343mm seems like a reasonably large amount, but it's all used up with the above tolerances. If it goes over (i.e. the contact wire ventures into the pantograph's horn area), there can be no assurance that the pantograph will always remain controlled.

Refer to *Figure 691* for an idea of the relative space allocation for the OHW contact wire portion (including tolerances) and for the *track* / *bogie* / *car roll* portions (tolerances).

When designing new OHW, the spacing of the OHW support structures (the *bay length*) is usually based on the appropriate *OHW Structure Spacing Chart* for that OHW system (which assumes no intermediate pull-offs within the bay).

An example for the standard OHW System 2 is shown back in *Figure 169*. The maximum spacing between structures is based on the track radius, from 28m spacing on 200m radius track, to 67m spacing on *tangent track* (= straight track, i.e. infinite radius). The structure spacing (bay length) gives a certain *blowout* value, and on a certain radius track (not tangent) it gives a specific track *versine* value. *Staggers* at each end of the bay counteract the effect of versine and result is a *mid-bay stagger* value, which ideally should (but cannot always) be something close to zero stagger (see below example). The blowout value is then added or subtracted to give a maximum *mid-bay blowout* value, and both values should be within the ±381mm maximum value (yellow area) in order to achieve pantograph security.

For straight track and down to 800m radius, the standard stagger value at support and registration locations is 250mm. On track curves tighter than 800m, this standard stagger value increases to 300mm (since there's then much less blowout to contend with).

Example:

According to the chart in *Figure 169*, for 800m track radius the maximum structure spacing is 50m, the resulting versine is 391mm, the standard stagger to use at both ends is 250mm and the resulting mid-bay stagger is -141mm. The blowout value is 192mm, so the mid-bay blown-out wire will be -141 ± 192 = +51mm and -333mm.
In this case, the larger -333mm value is well less than the -381mm maximum allowed, which is OK.

In the above example, the reason why the worst mid-bay blowout is well less than the maximum of 381mm, is at least in part due to the standard Structure Spacing Chart allowing for some future need to replace a (damaged) mast or portal leg structure by installing a new one up to 2m away. This action will make one bay 2m shorter (which is OK), and the other bay 2m longer (which then brings the mid-bay blowout closer to the maximum 381mm).

Note that the mid-bay stagger is -141mm, which is nowhere near the ideal zero stagger. To get zero stagger here would require the staggers at each end of the bay to be set at 391mm, which is no good as they need to be the standard 250mm (or 300mm if < 800m radius track), and because that stagger value already exceeds the maximum of ±381mm.

Note also that, in cases of twin contacts, this will result in the lateral position of 1 of the 2 wires at mid-bay being worse off and the other better off (by 25mm or 75mm, depending if the twin contact spacing is 50mm or 150mm respectively).

The main purpose of pantograph security is to ensure the contact wires are always there to control the pantograph's upward force, so it requires that *at least one of the contact wires* be < 381mm from the centre of pantograph.

Note that for cases of *uneven staggers* at each end of the bay on *curved track*, and also for *straight track* situations, the maximum blown-out wire position *may not be at mid-bay*. The "Blowout" program, within my OHW design tool "KF-ROW", can be used to calculate the maximum blowout in the bay and how far into the bay this blowout occurs. This blowout needs to also be less than ±381mm.

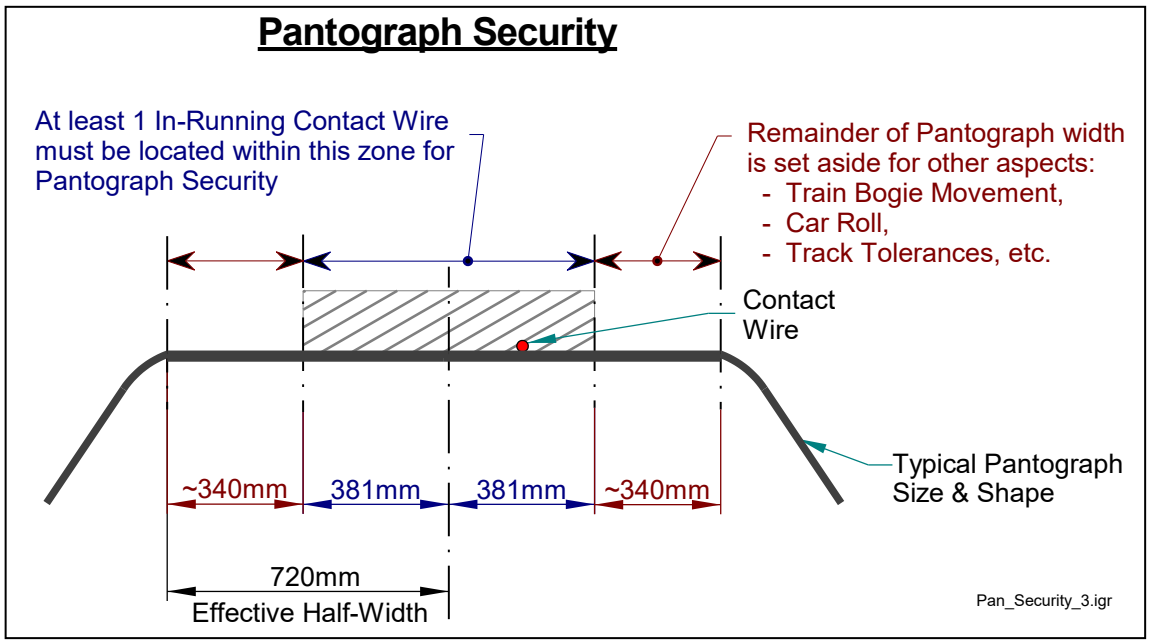


Figure 691 - Relative space allocation for Pantograph Security

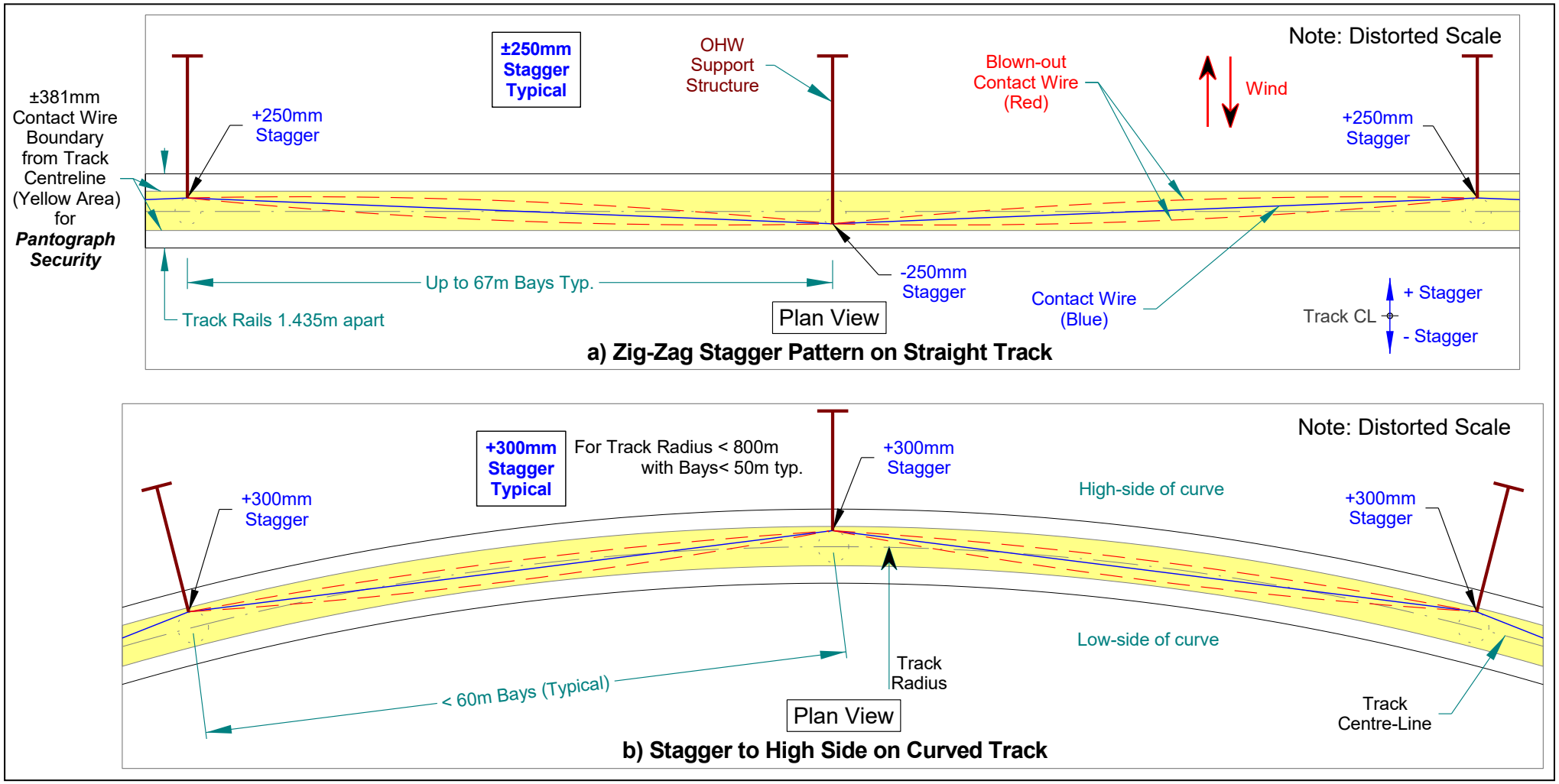


Figure 692 - Staggered Contact Wire for Straight & Curved Track

6.3.2.3 The Pantograph Gauge

For a long time now, a pantograph gauge has been used to confirm that there's adequate static clearance from a pantograph to nearby objects. It's essential to have such a gauge handy, and to understand what it actually means. But it assumes that there's no uplift influence from any other pantographs on the train, which is true for the passenger fleet (when stationary).

Referring to *Figure 693*, the gauge consists of:

- The outline (in **black**) of the "Maximum Combined Worn Envelope" pantograph shape as shown in *Figure 688*,
- A profile (in **blue**) above the pantograph, showing its "Raised & Oscillated" position, and
- A 150mm "Electrical Clearance" profile (in **red**) superimposed on top of the Raised & Oscillated profile.

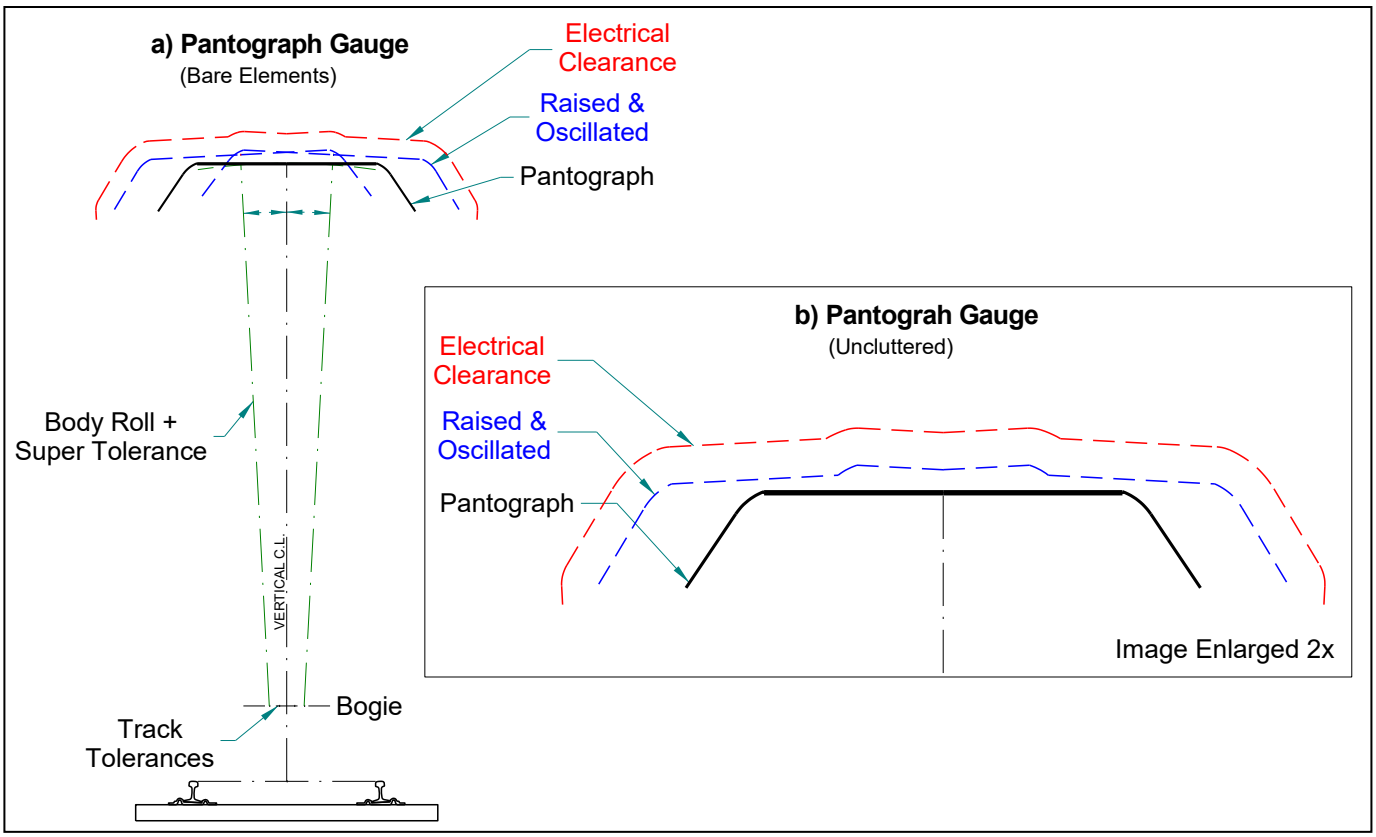


Figure 693 - Pantograph Gauge

The pantograph gauges are shown on various old drawings. There are a number of older drawn gauges in existence because the profiles changed with different contact wire heights and situations. This is because the higher the contact height, the greater the pantograph sway as well as the lateral effect of track superelevation tolerances at that height. Also, there are different track tolerances in certain areas, such as the tighter tolerances used inside some tunnels compared to outside.

For example, drawing EL0006186 shows the pantograph gauge for "Open Track: Tangent & Curved Track", which is by far the most common situation.

However, these drawings have virtually been superseded by the *PanGauge spreadsheet program* described in the next subsection below. This is because it can model all types of clearance scenarios to nearby objects, quickly and accurately, giving numbers and a diagram to help quickly understand the overall situation.

The composition of tolerances used in the calculation of the various profiles is shown in the upper right-hand table in the spreadsheet diagram (see *Figure 695*).

The pantograph gauge is mostly used to check for *clearances to objects that aren't energized at 1500V*, or objects at or near *earth potential* such as station awnings etc.
The *Electrical Clearance* envelope is used for this – no such objects should lie within this envelope. Refer to *Figure 694*.

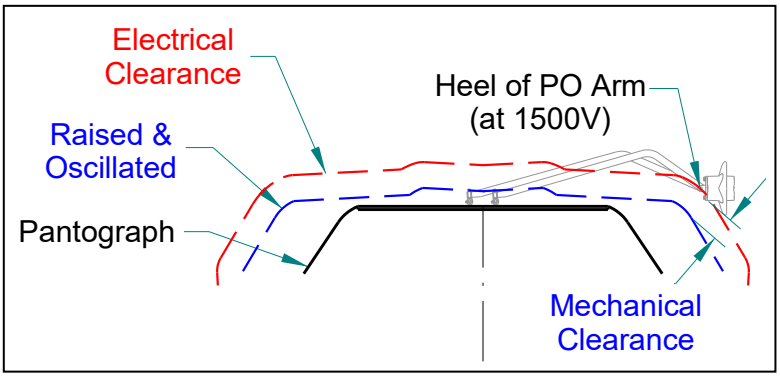


Figure 694 - Passing clearance to PO Arms

It is also used to check for suitable *passing clearances* to objects that are alive at 1500V, including the numerous pull-off arms that whiz by when the train is running. The *Raised & Oscillated* profile is used for this, but an additional 50mm or so needs to be added as required by the standards – I believe this is just to give a little more confidence (usually at no added cost).

6.3.2.4 The "PanGauge" Spreadsheet

To help understand and better control pantograph clearance situations, in the late 1990s a spreadsheet application was developed that allowed passing clearances to be checked from the "standard" pantograph to a nearby object. The application is called "PanGauge", and a typical output from this is shown in *Figure 695*.

It relies on the spreadsheet's chart-making ability to accurately draw a *pantograph shape* (in magenta), along with its *raised & oscillated* position (in blue), and its consequent *electrical clearance* envelope (in red). All 3 outlines are important when making clearance assessments.

In addition, the application also shows an ***indicative only*** "structure gauge" outline, in the hope that this might help to highlight other structure clearance problems in the process, and would give a better overall picture of the clearance situation. However, the fundamental purpose remains checking pantograph clearances.

The program was originally developed for assessing passing clearances from pantograph to station awnings for the 8 suburban platforms at Central Station – see *Section 6.4.6.1*. It turned out that, if the tracks were raised here, as they were planned to be (for gaining better passenger access to trains), then each platform had pantograph clearance issues. These issues were eventually all addressed with the help of the program, and the upcoming renewal and regulating of the OHW was to improve the situation substantially. (It was interesting to note that a few of the awnings appeared to already infringe structure gauge slightly.)

It is important to understand that the contact height controls the level of the pantograph, which can therefore affect pantograph clearance to nearby objects. So, if the contact height in these crucial areas is proposed to change, then the altered clearances need to be checked out.

The program relies on knowing the "design" position of track, and this usually requires some accurate survey to be undertaken at specific locations. The design position of track has 3 aspects:
its *lateral* position (in relation to the object), its *height* (rail level) and its *superelevation*.

A subsequent update to the program allowed for a second track to be included (with the term "Dual" now in its title). The clearance to objects located *between* tracks (such as drop verticals) could then be accurately assessed, as shown in *Figure 695*.

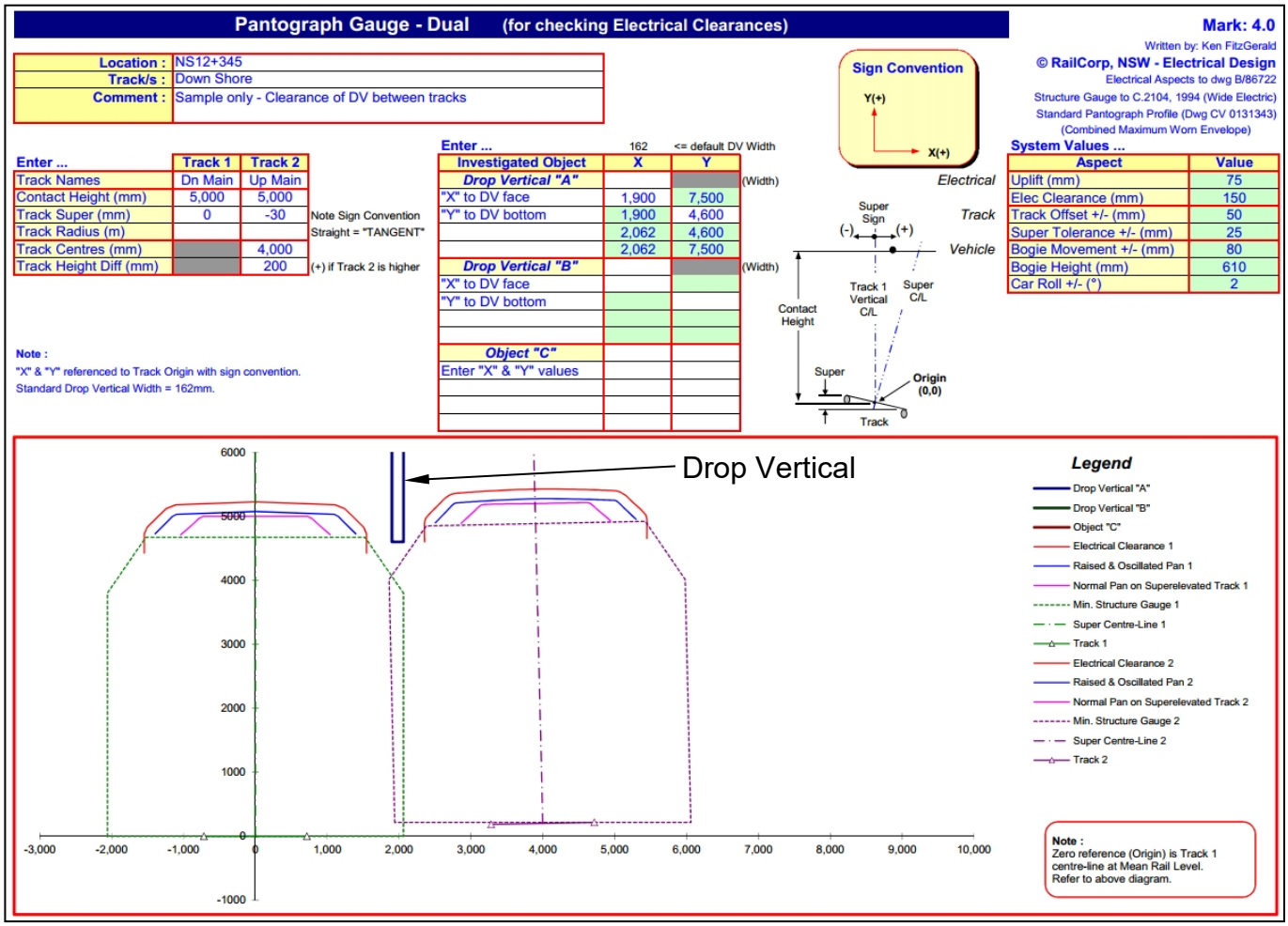


Figure 695 - "PanGauge" output showing DV clearance between tracks

6.3.2.5 Pantograph Height

Each pantograph needs to be freely able to vary its height from pantograph head to track, as directed by the contact wire height.

While the "normal" (design) contact height is 5.0m these days (*Figure 696*), this height can vary:

- Up to about 5.8m, e.g. at level crossings, and
- Down to about 4.57m, e.g. in situations of very low fixed-anchored wire under the worst (hot) conditions. This is only 150mm above the roof of a double-deck train. (Note that it's reduced even further to 4.52m in some City Tunnels under *special approval*.)

Figure 696 - Pantograph at 5m Contact Height (Epping)

See *Section 2.7*, *In-Running Contact Zone* for more details on these heights. (The above maximum and minimum contact heights are stipulated in EP-08000001-SP, "OHW Standards for the Electrification of New Routes".) Refer also to *Section 3.1.2.5*, *Contact Height*.

To maintain a good low-resistance sliding electrical connection, the pantograph should exert a relatively constant upward pressure (~130N) onto the contact wire, when this wire is located anywhere between these upper and lower height limits.

6.3.2.6 Pantograph Clearances

The OHW contact wire controls the height of the pantograph. So, the contact height can play a crucial role in tunnels, stations and where any other object is in the close proximity to the horn of the pantograph.

In a typical breadloaf-shaped *tunnel*, the design contact height would normally be set at about 4.75m above track, and this usually gives suitable lateral diagonal clearances to the curved tunnel lining near the pantograph.

If the contact height was increased to 5.0m for instance, then there's a good chance that the upper edge (horn) of the pantograph may infringe the 150mm electrical clearance from pantograph to tunnel lining, or worse still, there may be a direct collision with the lining.

Again, the height of the contact wire is critical in understanding and controlling the situation.

Clearance from pantograph to *station awnings* is especially important, and checks need to be performed to ensure there are suitable clearances. This can be tricky for fixed-anchored OHW under cold temperatures / high catenary tensions, where the catenary will drag the contact wire up *at mid-bay* and thus may reduce pantograph clearances to nearby awnings already in close proximity – see *Section 6.4.6.1*, *Pantograph Clearance to Platform Awnings*.

6.3.2.7 Pantograph Problems

Over the decades there have probably been numerous OHW / pantograph interface issues that had to be worked through, to ultimately achieve a high level of reliability (for train running). I mention only a few problems here (that I know of since the 1980s).

SECTION INSULATOR STRENGTHENING

Section 5.1.5, *OHW/Pantograph Compounding Problem* had previously talked about the tendency, driven by need, to "beef things up" – the OHW made heavier and stronger, then the pantograph likewise, then the OHW, then … etc.

The Type 6 SI was trialled in the mid-1980s in a search to find a better performing SI than the Type 5 SI, which was deemed unsuitable for higher speed main line traffic.

But even the superior Type 6 SI needed to be *strengthened* in certain parts, so as to cope with the punishment dished out from any heavily worn carbon strips or badly-adjusted pantographs travelling at speed. (Quite a few SIs had failed before the strengthening was ultimately mandated, but the changes proved to be an effective long-term solution to this problem.)

Around the 1980s a number of the Type 5 SIs were failing in service – their runners were fracturing at the point where they were bent up about 45° in order to form the arcing horns on each side of the SI. Probably the biggest factor leading to this damage was the state of the pantographs of the day, which had a heavy frame and head, and could not trace the contact wire that well, and would hit hard against any non-ideal contact level. Also, any excessively-worn carbon strips were seen as a culprit, with significant carbon strip wear towards the centre of the pan head (as happens over time) causing the carbons to strike hard in areas like the gap between the arcing horns of the Type 5 SI (where the damage and fractures occurred).

In addition, in the case of freight trains, the closely-spaced configuration of pantographs was not ideal, with the worst case being locomotives having all pantographs up in close proximity (2 pantographs per locomotive and up to 4 locomotives connected together at the head of the train = 8 pantographs). Each pantograph disturbs the OHW, which the following pan has to pass through, so the last pantographs used to perform badly at speed – arcing and sometimes moving wildly up and down. It was an enormous ask for an SI to cope with this treatment as the successive pantographs passed through. Refer to *Figure 498* for example. With no more electric freight trains however, this is no longer a problem for Sydney.

The newer single-arm pantographs, installed on some of the existing and all the newer fleet from about the 1990s (?), were a vast improvement compared with the old pantographs. I'm guessing the improvements include the following:

- They incorporate effective *primary and secondary suspension systems* and *damping* (to reduce any oscillations). The long arm of the primary suspension is better able to cope with the large excursions in contact height e.g. rising to go over level crossings (to about 5.5m), and lowering to go under overline bridges (to about 4.65m). The secondary suspension better traces the smaller imperfections in the contact level, such as at hard spots, kinks, SIs, etc., with less or no arcing taking place. So combined, they are better able to trace the level of the contact wire throughout the wire run, even with imperfections in this wire. Damping any wire oscillations is most important too.
- They are *lighter*. The lower mass and thus inertia of the pantograph mechanism is more capable of tracking the changing heights of the contact wire.
- They are *newer*, meaning that the bearings, etc. are less likely to stick or offer excessive friction. The pantograph head is also more likely to remain parallel to the roof top. And the newer technology obviously brought benefits with it too.

The strengthening of the Type 6 SI continued until 2013, when it was determined that the heavier copper runner sections that were then supplied by the manufacturer, should be strong enough by themselves to cope with the now lighter and much-improved pantographs. The modification to include steel angle strengtheners added much weight (and cost) to the Type 6 SI, and this was no longer needed. It was a good outcome for the OHW, for the trains, and ultimately for the taxpayer. Refer to *Section 3.6.2.4*, *Modifications*.

BRIDGING ELECTRICAL SECTIONS

From an OHW perspective at least, the distance between the pairs of carbon strips should ideally be as small as practical. So, when they pass under a section insulator, or through a feeding or open overlap, with *different electrical sections both sides*, a smaller spacing between carbon strip results in less time (distance) that both electrical sections are electrically bridged out.

Bridging-out different electrical sections is a necessary evil in these situations, so the less time the better (for all sorts of reasons).

Note that OHW overlaps pose a greater potential problem than section insulators in this regard, because the length of wires of different electrical sections being bridged by the pantograph is so much longer in an overlap.

This is discussed further in *Section 3.6.0.5*, subsections: *Shorting Distance*, *Damage Due to Pantograph Bridging* and *Jumpering an SI*.

See also *6.5.1*, *Relative Positions of Signals & Open Overlaps*.

OHW Damage

A pantograph that somehow rises above the contact wire can deliver significant and extensive damage to the OHW, the pantograph and any other pantographs that may follow.

See *Figure 697* as an example of a damaged single-arm pantograph from a Tangara at Epping in 2012. Needless to say, the amount of OHW damage was significant.

I'm not sure whether it was the pantograph or the OHW to blame for this one.

Figure 697 - Damaged Pantograph

Carbon Strips

Just a few observations ...

Wear

The carbon strips tend to wear within about ±300mm of the centre of pantograph, essentially as a result of the staggered contact wire zig-zagging across this area for most of the time. The wear is in the shape of a shallow "dish", and this effect can be seen in *Figure 698* (and *Figure 63*).

Figure 698 - Dish-shaped wear in carbon strips

Such wear can cause problems at *section insulators*, which are setup for (and expecting) a flat set of carbon strips. Refer back to *Figure 407* and its surrounding text for one such problem. *Section 5.1.5* details yet another issue.

If the carbon is worn sufficiently, the contact wire may begin to connect with the stainless steel carriers that hold these strips, and this can cause rapid wear to the underside of contact wire. Fortunately, these days some (all?) pantographs are equipped with pneumatic "drop" mechanisms that cause the pantograph to completely lower when the strip wears below a certain level. Excellent!

Missing Segments

There have been a number of instances over the years where a short segment of carbon strip became missing from the pantograph carrier. See *Section 5.5.3.2* for instance.

Some (all?) of these segmented strips are held into their carrier by stainless steel threaded rod and nuts, and these nuts can sometimes become loose. But they are also vulnerable to damage caused by badly installed or damaged OHW equipment, notably if parts hang below the bottom of the contact wire level as fast pantographs pass through (bearing in mind that there are thousands of kilometres of OHW in the network). This damage to the carbon strips can even come from outside interference, with things like tree branches breaking off and blown or dropped onto the OHW, and ultimately hanging from the contact wire, for the next pantograph to strike (often at reasonably high speed).

A missing carbon segment can play havoc with the OHW because the contact wire can become somewhat trapped within the confines of the recessed "notched" area of missing carbon (with its abrupt vertical sides). The pantograph head can rotate longitudinally to a small degree so that both carbon strips can share the sliding connection with the contact wire. Even if the adjacent parallel carbon strip is intact, damage can result (to contact wire and to pantograph) when the contact wire gets "trapped" in the space provided by the missing carbon segment, but is subsequently forced to sweep across the pantograph as it travels through the bay. It would likely get released from this lower area, only to become trapped a short time later when it again tries to sweep across (which can happen within the same or next bay). In the process, the stresses to the pantograph components and to various OHW fittings (including the contact wire) must be quite large, and would likely lead to pantograph and/or contact wire (or other hardware) failing in some way within a relatively short period of time.

It's possible that the contact wire could also quickly wear against the metal carrier that holds the (now missing) carbon strip segment as the train proceeds.

A "Problem Example" was given back in *Section 4.1.0*, and this included a photo – *Figure 487* – of a pantograph with some missing carbon segment. This problem was apparently caused by an OHW clamp – when the OHW was hot, the clamp would sometimes lower into the path of the pantograph, and it was argued that this was the reason why the carbon strip was clobbered, damaged and became missing. This type of OHW problem is difficult to find.

6.3.3 Train Maintenance Facilities (Car Sheds)

Train maintenance facilities require the train to enter the shed so that work can be carried out on the vehicle. But what to do with the OHW above the train, which can hinder access to the top of train and offer safety issues?

6.3.3.1 OHW Terminated Outside Facility

The train can be under normal electric power up to the shed, then be pushed or pulled in (after pantographs are lowered) because the OHW terminates on the outside of the shed.

In this case, a special skid arrangement is installed for *over-run protection* to help deal with pantographs that are inadvertently still up when moving the train into the shed. There's no problem with OHW inside the shed because there is no OHW. Refer further back to *Figure 458* (slightly inside) and to *Figure 459* for instances.

6.3.3.2 OHW Passes Inside Facility

Some facilities have the OHW continue into the shed. A switched section insulator is installed immediately before the entrance so the live OHW can be switched off locally.
See *Figure 699*.

If access to the train roof is required then the switch is interlocked using a special "Annett Key" or similar safety system, to bar access to the area above the train until the power has been removed and the OHW electrically connected to rail.

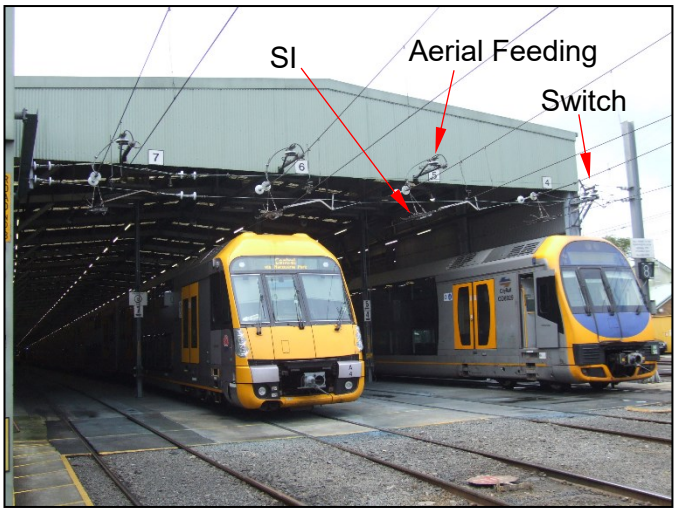


Figure 699 - OHW passing inside facility (Hornsby M/C)

6.3.3.3 Overhead Conductor Rail OHW

The recently-installed Auburn Maintenance Facility includes yet another OHW system – the swing-away "Overhead Conductor Rail" system (or "Solid Bus"). This became operational in 2010 for maintaining the (then new) Waratah train fleet.

See *Figure 551* in *Section 4.3* and also *Figure 700*, taken during its construction.

Figure 700 - Swing-Away OHW (Auburn M/C)

Here, the multiple tracks entering the facility each have their respective normal OHW runs terminating at the shed entrance – see *Figure 701* (at that stage unfinished). It is then taken over by a contact wire held in the bottom of an extruded aluminium section – the *conductor rail* – which passes all the way into the maintenance facility. The solid bus is self-supporting between its own supports, which means that neither the aluminium section nor the contact wire is under any mechanical tension.

The whole contact system inside the shed is supported by several special solid post insulators, spaced about 10m or so apart. These supports are designed to swing the contact wire from being above the centre of track, over to the side and out of the way of the maintainers, who then have unimpeded access to the top of the train.

Figure 701 - Special OHW anchorage outside Maintenance Centre - under construction (Auburn)

In this way, the train can move into the shed under its own power. Then a switch, located outside the shed and coupled to a section insulator for that track, can switch off the power and rail-connect the OHW. With the pantographs lowered, the OHW can then be swung laterally almost 90° out to the side, away from the top of train as required.

Of course, a special protection scheme needs to be adopted to ensure maintenance staff can only proceed to the elevated work level and to the top of the train when it's safe to do so.

6.3.3.4 Earthing & Bonding

Earthing and bonding issues need to be addressed in maintenance facilities – you typically can't mix the 1500V dc system with the ac power system (for tools, etc) inside the facility.

Also, any electrolysis corrosion issues need to be handled by proper design of the 1500V bonding arrangement.

6.4 CIVIL INTERFACE

There are many areas where the OHW interfaces with civil structures, be they above, to the side or below the OHW infrastructure. (The structures that are designed specifically to support the OHW are not included in this description – they are covered as part of the OHW system in *Section 3.3*.)

6.4.1 Overline Bridges

Overline bridges, including footbridges, can cause issues with the OHW over time, primarily because they're usually located in close proximity above the OHW.

Probably the major concern with road bridges is the spillage, onto the roadway, of chemicals being transported over the bridge. There is probably very little that can be done to control such spillages. These spilt chemicals can leach into the bridge and eventually drip onto the OHW infrastructure (and track).

If the chemicals are even slightly corrosive, they can slowly dissolve any galvanised coating on steel parts, leading to rusting steelwork and thus a reduced (and uncertain) service life.

Certain chemicals can also cause the *copper* catenary and/or contact wires to turn pink and appear to be annealed, or to turn green (e.g. copper sulphate when affected by sulphuric acid from car batteries for instance). There have been a few times that I'm aware of where the catenary wire had turned pink in localised areas under a bridge, and because of the doubt and consequent fear that it may actually be signs of the copper wire "annealing" (horror!), sections of the affected catenary wire were renewed. Such action requires the installation of splices which can unfortunately then reduce reliability and increase ongoing maintenance effort.

The chemicals can also leach or react with other salts over time, to eventually form what appear to be "stalactites" suspended from under the bridge. See *Figure 702* for example. If they appear directly above the catenary wire or other live parts of the OHW, it can reduce the electrical clearance to the OHW and possibly cause a hazard. The catenary wire can move up (and down) a small amount, e.g. when pantographs pass through, or at different temperatures in a fixed-anchored system.

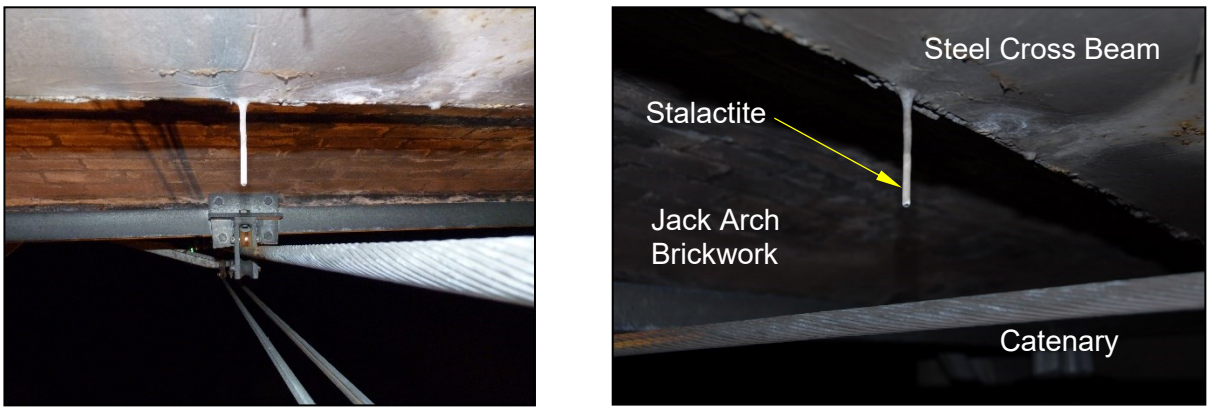


Figure 702 - Stalactite reduces Catenary clearance

If the catenary momentarily touches the stalactite (or water from its bottom end), it can liven parts of a steel bridge, and the potential can be transferred elsewhere through attached steel fencing, etc. Although it's quite a remote probability of growing a stalactite to such a length that it causes this problem (why doesn't the train-generated wind snap it off?), this can obviously be a significant safety issue, and apparently it was argued that this sort of thing did happen recently. If it does occur, the intermittent nature of any such livening-up can also make it difficult to find the culprit. (You would think that the fragile, brittle stalactite would simply vapourise or snap off in contact with the live wire though.)

Most OHW-related problems that occur with overline bridges can also happen inside tunnels.

The various areas of concern when designing, constructing and maintaining the OHW under overline bridges (and inside tunnels) are listed below.

- Finding appropriate OHW support attachments to the structure of the bridge/tunnel.
- Attaining suitable electrical clearances in all cases, and keeping them.
- Determining the need for, and provision of, *safety screens* and/or *bonding circuit* (with ways for testing it). From an OHW perspective, it is desirable to avoid the need to bond (for various reasons). But bonding does enhance the electrical protection of the OHW.
- Profiling of the OHW to the bridge/tunnel (typically requiring gradually reduced contact and catenary heights as the OHW approaches it).
- Ensuring that suitable "Isolating Panels" are installed in any adjacent line-side metallic fencing.

Some of the approaches for supporting and registering OHW under an overline bridge are discussed in *Section 3.2.5*.

For more information on the requirements of safety screens on overline bridges, refer to Standard EP-08000007-SP, "Safety Screens for Bridges Over 1500V OHW Equipment".

6.4.2 Tunnels

With regard to the OHW, the important part of tunnels (and overline bridges) is that area mostly at or above train carriage height. Refer to *Figure 703*. It's in this area where the OHW needs to be more regularly *supported* above the track (with necessarily shorter bays), and it also needs to be *registered* with some form of pull-off arm located off to the side.

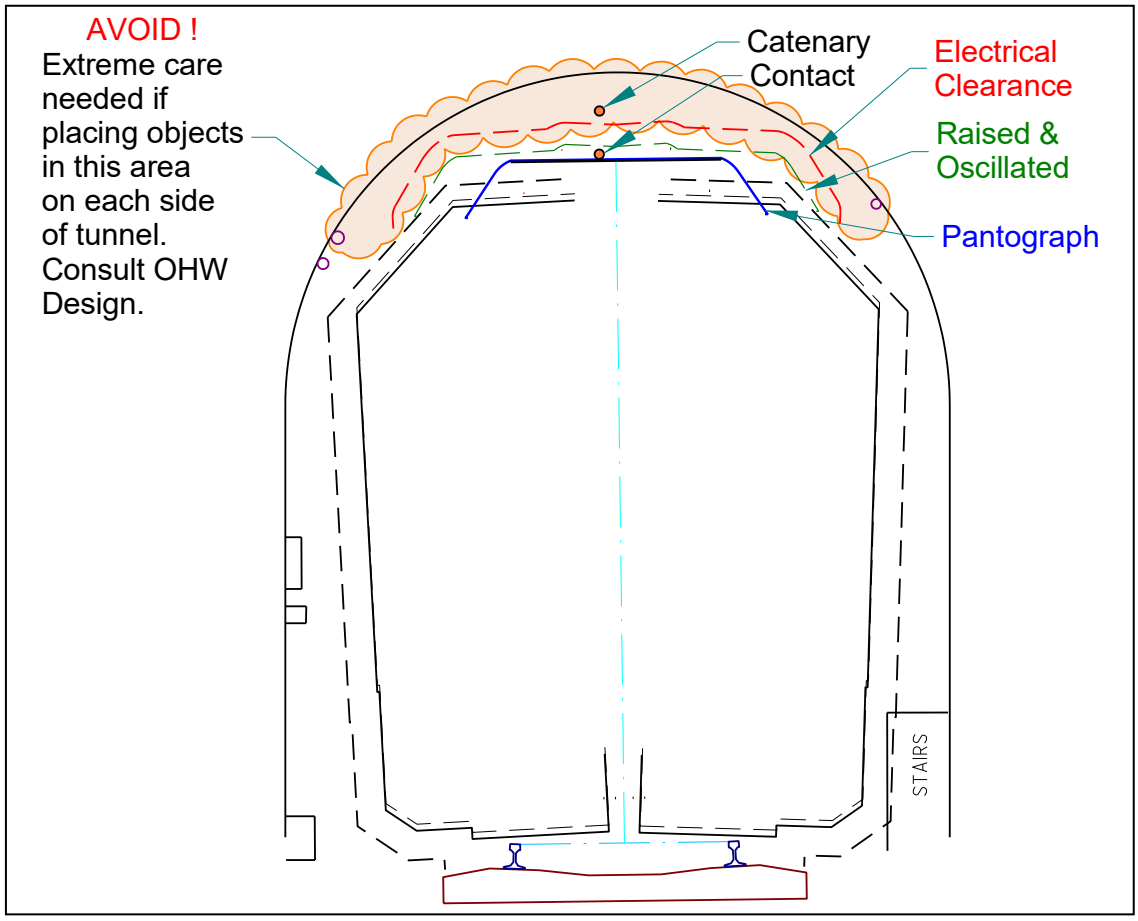

AVOID !
Extreme care needed if placing objects in this area on each side of tunnel. Consult OHW Design.
Catenary Contact
Electrical Clearance
Raised & Oscillated
Pantograph
STAIRS

Figure 703 - Critical area for placing services in tight tunnels

These situations typically have the heel end of the pull-off arm (remote end to the contact wire connection) at a height of about 4.8m (for 4.75m contact height), and laterally offset by about 1.35m or so from the superelevated track centre at that height.

On a typical "breadloaf" tunnel shape, this usually places the end of the live arm close to the tunnel lining, with very little room for insulation (150mm or so is needed for the insulator). Carving out pockets in the tunnel lining is one (costly) solution. The *Mark-3 Tunnel Cantilever* (for regulated OHW only) was designed to help in these situations (without the need for creating pockets in the tunnel lining).

Both of these functions – wire support and wire registration – need to happen usually within very limited space, and it is this limitation that drives the various types of compact support & registration equipment here. Refer to *Section 3.2.5* for bridge support & registration arrangements and *Section 3.2.6* for tunnel arrangements.

Figure 703 shows a diagram of a typical breadloaf-shaped tunnel (this one is at North Sydney tunnels). It shows very limited space in which to place other services above the upper half of a train. The diagram was generated using survey data at a particular location, which picked up a number of services already installed in the upper half of the tunnel (shown as small circles: 2 on the left side and 1 on the right side).

Great care needs to be exercised if placing services in the clouded orange shaded area on this diagram. This is normally the domain of the OHW equipment, although other services can and have been located above the train, e.g. leaky coaxial cable for train communications and mobile phone coverage throughout the twin-track Airport Tunnel. Special clearances from all OHW fittings, including DVs, are stipulated in this case, because any unintentional connection to the OHW system may make it possible, under some adverse situations, to transfer the 1500V dc (or its leakage currents) elsewhere, with potentially dire consequences.

One real problem here is the wrong perception that the OHW catenary and contact wires are located at the tunnel centre, well away from the tunnel sides, and so there's apparently no problem installing a service off to the side when up at this level. However, when a pantograph comes along, the 1500V hazard *transfers* out to the pantograph edges which, for a dynamic pantograph, is quite a long distance from track centre – refer to the red "Electrical Clearance" profile in *Figure 703*. This hazard may not be obvious when walking through the tunnel while planning for the location of a new service (cables, etc.), thus it can be a trap for the unwary. See in particular *Section 5.7.6*, *The Travelling Pantograph*.

So, any time services need to be planned for location in the upper part of the tunnel, OHW Design (and Civil Design and probably Track Design and others) need to be involved, to help make sensible decisions for the location of these services that meet the various standards.

Some of the approaches for supporting and registering OHW within a tunnel are discussed in *Section 3.2.6*, and example situations are covered in various parts of *Section 4*.

6.4.3 Airspace Developments

Airspace developments are typically flat ceiling structures that are built *above* the train tracks. This makes use of this otherwise unusable space, often in highly desirable locations (thus justifying their existence).

Quite often, railway stations are included as part of the airspace development, and a good example of this is at North Sydney Station, with high-rise commercial buildings built nearby above the tracks.

The existence of all sorts of services, including air conditioning ducts, advertising display boards, steel pipework for fire sprinklers, lighting, architectural ceiling panels, etc., can affect, and be affected by, the design of any OHW to be installed in the area.

Great care should be given, particularly with regard to *earthing and bonding issues* for any OHW structures (drop verticals), support & registrations arrangements and catenary/contact anchors. All surrounding infrastructure should remain well clear of OHW equipment.

In this environment, any local *earthing system* must not be connected to any *OHW bonding scheme* (and vice versa), even though there may be great temptation to do so (for whatever wrong reason). There may even be schemes available (such as employing secondary and tertiary insulation) that can obviate the need for running bonding wire, and this can have merit here. However, in this unusual situation the adopted scheme needs to be endorsed and signed-off by experts in earthing and bonding for dc OHW in the rail environment.

6.4.4 Underline Bridges

Underline bridges are those structures that allow rivers, roads, footpaths, etc. to pass *under* the railway tracks. Some examples are given in *Figure 704*, *Figure 705* and *Figure 706*.

Figure 704 - Regulated OHW installed on Stanwell Park Viaduct

The main concerns with OHW installations on underline bridges and viaducts are:

- ***Location of OHW support structures***. There are usually only limited places for the legs of OHW structures to be located, and they include on bridge piers where the mechanical loads can be directly transferred to ground (*Figure 705*). And the OHW structures should be designed in a way that does no damage to the main structure, especially over time.
- ***Obtaining suitable electrical clearances***. If the bridge has some form of overhead structure, such as the "lattice" steelwork of the main bridge in *Figure 706*, it needs to be suitable for the installation of the runs of OHW conductors across it. And in particular, there needs to be suitable places on the bridge (on beams, steel angles, etc.), for the installation of the various support & registration attachments, whilst also providing suitable OHW electrical clearances to the bridge steelwork.
- Consequent ***electrolysis considerations***. Several options usually exist for the provision of electrolysis mitigation, and these need to be properly thought through during the design stage and implemented, so as to avoid damaging the asset. Options include:

  - Bonding each *individual structure* with a spark gap to rail. This may be time consuming to periodically test. Unfortunately, bonding can also provide other unwanted adverse effects.
  - Connecting *groups of structures* together in a common bonding circuit (with connection to each structure either by bare aerial wire or untensioned cable), and with each unique circuit group connected to rail by a single spark gap (which is ideally located at a convenient place). This would offer quicker periodic testing of the (now

single) spark gap. But if a fault is detected, it may be slower to locate the cause (e.g. faulty insulation). Refer to *Section 3.12.0.5*, *Using a Common Bonding Circuit*.

- Provision of *secondary insulation* or *tertiary insulation schemes*. Secondary insulation may help to isolate earthing and bonding issues. Tertiary insulation may avoid the need for any bonding circuit to the track (note that a bonding circuit carries its own risks). Refer to *Section 3.12.0.5*, *Levels of Insulation*.

Figure 705 - OHW Support / Anchor Mast installed on Viaduct

Figure 706 - Fixed-Anchored OHW across Hawkesbury River Bridge

6.4.5 Level Crossings

I understand that the NSW Railways had a policy, possibly from about the 1950s (?) onwards, of removing as many level crossings from the rail system as was deemed practical. So, in Sydney's electrified network there are only a handful of ***public level crossings*** remaining. This is a truly remarkable outcome, and it was probably driven by at least 2 obvious desires:

- To alleviate the significant safety issues involved when road and rail vehicles compete for a common passage at the same level.
- To provide a free flow of traffic for all vehicles involved, and save peoples' time and frustration.

Overline or underline bridges result in *grade separation*, and can provide the above 2 benefits. The long-term benefits provided by adopting this policy over the ensuing decades must have been enormous.

But there are many more ***private level crossings***, and these are in all sorts of odd locations. Fortunately, the volume of traffic is likely much less than for public level crossings, meaning that the likelihood of problems, due to the several risks involved, should also be significantly less. (The big costs to provide bridges can't always be justified, and may not always be practical as well.)

At *level crossings*, the Overhead Wiring infrastructure is quite susceptible to damage from over-height vehicles passing across the track and under the contact wire/s, and there are several things to be said in this regard. Note that OHW standard EP-08000012-SP, "Level Crossings – OHW Clearance Requirements", stipulates current requirements, and should be referred to in connection with any level crossing issues.

The main *control* for preventing a vehicle touching the live contact wire is that this (lowest) wire be designed to have at least 1.0m vertical clearance from the highest part of any permissible crossing vehicle – including its load – to the contact wire in its worst case (lowest) position. This is regardless of whether it's a public or a private level crossing.

Apparently in the electrified area, the maximum motor vehicle height permitted on roads (including their load), without a permit for excess vehicle dimensions, is 4.4m. (Obviously tall vehicles can also affect all sorts of other infrastructure, including 230V service lines to peoples' houses, underline bridges, etc.)

In terms of the OHW, this normally means increasing the contact wire height locally to 4.4m + 1.0m = *5.4m minimum* (at hottest temperature if fixed-anchored OHW). To achieve this, the contact height needs to be progressively ramped up from a standard height (usually 5.0m), and this would typically take about 200m of track to do so, on both the approach and departure sides of the level crossing, and for each track affected.

The OHW support structures in this area may need to be designed taller to cope with the higher catenary and contact heights.

As far as the OHW is concerned, reducing the number of level crossings to the bare minimum is a big benefit in terms of safety risk. This is because of the serious adverse consequences if a high vehicle and/or its load strikes the contact wire, and either:

- Causes the contact wire to snap and fall to ground (instead of track), and not trip the DCCB protection, in which case this wire may remain alive at 1500V, or
- Causes the contact wire to stretch or become detached from the catenary (i.e. damaged droppers), or other mechanisms that can lead to the live contact wire lowering to a height

that may then be reached by people, either directly or indirectly through some conductive object.

WARNING BARRIERS (OR PORTALS)

Sometimes level crossings on public or private access roads at critical locations also include special *warning barriers* (or *warning portals*) that provide a physical "gauge" (e.g. horizontal beam) before reaching the area of restricted height.

The intent is that any over-height vehicles will strike the barrier and hopefully alert (wake up) the driver to the looming hazard. This is really a last line of defence. Unfortunately, not all situations have the luxury of having sufficient space before the crossing, for this to be effective at stopping such vehicles before touching the OHW.

CONSEQUENCE TO OHW

It can be difficult to predict the outcome of a vehicle striking the OHW at a level crossing. If the vehicle snags the wire and continues (without the driver knowing what's happened), the wire is likely to stretch and ultimately snap (break). If the vehicle brushes against the contact wire without snagging it, then this is less likely to break the wire, but it could cause the wire to be damaged in some other way and also come out of alignment locally. Deep gouges in the bottom of the damaged contact wire, for instance, will likely cause some degree of damage to the carbon strips of successive pantographs (with accompanying arcing), until the gouges are worn smooth over time.

The amount of OHW damage is likely to be related to how far the vehicle continues after the collision, before stopping. The OHW is a linear asset, and so the damage can transfer problems in both down and up track directions from the point of impact, possibly for hundreds of metres. Some damage may occur even kilometres away on the same or adjacent wire run (if overstressed components go out of adjustment).

Because vehicles have insulating *rubber tyres* and there's no metallic connection from vehicle to track, it may be unlikely that the DCCB protection will trip the affected OHW section. And so the live OHW poses a real hazard, especially if the driver or an occupant steps out of the vehicle, or someone else touches the vehicle while it's also touching the OHW.

The hope is that the broken contact wire touches the steel track and stays there – this should trip the DCCB protection and de-energize the situation, making it safer.

If the vehicle only strikes the contact wire (with the catenary higher and further out of the way), then a likely outcome would be the successive *droppers breaking* ("unzipping") and in-span feeders uncoiling, possibly snapping in the process. In this case, and provided the vehicle stops quickly, the contact is no longer supported by the catenary wire for a distance. If only a few droppers are broken, the contact wire is unlikely to sag more than 1m or so from its normal height. But if many droppers snap, then the length of unsupported contact wire could sag to ground or just above it (and possibly within peoples' reach).

If the resulting undroppered *contact wire snaps* then it can tend to coil unpredictably (it tends to take on its original coiled shape from being wound on the wire drum at manufacture). This uncontrolled wire can be a real hazard, especially if it touches a nearby fence or other metallic object, leading to a *transfer potential* hazard. (The catenary wire, with regular intact droppering, should normally help to restrict any lateral movement of an untensioned contact wire.)

If the vehicle strikes both the contact and the catenary wires, then much more damage is likely for the entire run length as well as any OHW that interfaces the affected run/s, e.g. at turnouts to sidings, at crossovers and at overlaps.

Damage to contact wire can affect other OHW elements further away from the site of the incident. A patrol is warranted over the full length of the affected wire runs (and a bit more) to determine all subsequent damage and any other corrections needed, e.g. realignment of fittings. Some corrections may be subtle, such as catenary saddle clamps sliding along the catenary at a fixed mid-point anchor under a bridge (and therefore not locking the catenary from drift).

Red warning signs with white lettering show essential height restriction information to road traffic well before passing under the OHW on each side of the level crossing. Refer back to *Figure 462* for instance. It's important that these signs not be obscured by other objects in time, including bushes or trees. Or that the information on the signs be defaced by vandals or otherwise altered. Refer to *Section 3.11 Signs*.

As mentioned above, under certain circumstances *warning barriers* are required to be installed on each approach side before the level crossing, in an attempt to force compliance. Refer to the above standard.

Example:

Figure 707 includes 3 photos of a situation that happened on the South Coast in 2008, where the lift arm of a truck snagged the contact wires when passing through a level crossing. (I assume the photos were taken by the Illawarra District maintenance staff?)

It seems that the truck made it to the other side, because the lower right picture shows damage to the Type 1A cantilever supporting OHW for the closest track (its horizontal boom was bent back at right angles to itself, which takes quite a bit of force to achieve).

The driver must have eventually realised that his truck was tangled in the OHW, and he reversed all the way back towards the start of the level crossing (maybe hoping all the damage gets undone?). But this action brought one of the snagged contacts with him (as shown in larger photo).

Quite a lot of damage resulted, mostly to the OHW equipment – including to the 4 contact wires (it's a twin contact regulated OHW system down there), in-span feeders (lower left photo), droppers, cantilevers (lower right photo), etc.

The contact wire must have also swung over and touched the station awning located nearby, because there were significant arcing splash marks on the galvanised steel facade. This may (or may not) have caused the protection to operate.

In any case, it is possible for the OHW to remain alive in this situation, which means the truck would also be alive at 1500V until someone turns the power off at the Electrical Operating Centre. (It's likely that the ac electrical protection mechanisms of a 25kV OHW system could have advantages in this situation.)

This is a good example of why, at least from an electrical/OHW perspective, level crossings are potentially dangerous and should be designed out if at all practical, because it's extremely difficult to *always* prevent *all* people from doing the wrong thing (even though it may be inadvertent).

Figure 707 - Truck arm snags the OHW at a Level Crossing

6.4.6 Stations

There are a few OHW-related aspects when dealing with railway stations.

6.4.6.1 Pantograph Clearance to Platform Awnings

Quite often a station roof will span all the way out to cover the edge of the platform, to help shield passengers from rain as they alight from or board a train.

This means that, although the OHW itself may be well clear of the awning, the reduced clearance from the edge of passing pantographs may be a problem. The clearance depends on the height and shape of the awning, and how far out towards the platform edge it stretches.

But the contact wire *height* can also influence the clearance from the outside edge of pantographs to these particular awnings, and this needs to be taken into account during design of the OHW and/or design of the station awning. Making changes to the contact height

without checking on its possible effect on pantograph clearances can be a trap in this regard.

EXAMPLE: CENTRAL STATION

A good example of this pantograph clearance issue happened at Central Station in the late 1990s, when it was proposed to raise the track to provide "level access" so there's not so much of a step when boarding or alighting from a train (which can otherwise be a significant problem with passenger access). Around the same time, all the OHW in this area (from Goulburn St Parking Station through Central Station to Redfern) was being renewed as a regulated tension system (instead of the previous old fixed-anchored OHW).

All 8 "Suburban Electric" platforms were affected (Platforms 16 to 23), and each platform awning had a vertical member that apparently already came down close to the edge of pantographs. Unfortunately, the OHW here was already low (~4.65m), so raising the track meant also raising the OHW in sympathy, and this would have led to further encroachments to the already substandard pantograph clearances to some awnings (not all were affected).

As it turned out, some awnings seemed to also be either close to or infringing Structure Gauge by a small amount, and this situation would have been made even worse by lifting the track. (Note that this had nothing to do with the OHW.)

Refer to *Figure 709*, which shows a snapshot, at several support & registration locations, of the bottom of awning causing the already *existing* inadequate clearances for *Platform 21* (this was probably the worst of the 8 platforms for pantograph clearance). All resulting clearance diagrams, produced during the investigation during the OHW design, were based on accurate survey taken at the time. On the diagrams, the awning is shown as the (almost) vertical panel in magenta colour, and approximate structure gauge is shown in the green outline.

Figure 708 - Pull-Off Span at SW0+139 Up Illawarra (right side)

The greatest infringement was at SW0+139 on Up Illawarra track – a photo of this location is given in *Figure 708*. Note that around the same time, the vertical awning panels were removed to be refurbished (from corrosion I think, or was it timber rot?), leaving only the regularly-spaced arc-shaped brackets as seen in this photo. Of course, mid-bay pull-off locations saw the most changes in contact height due to the fixed-anchored tensioning – cold weather yielding the worst pantograph clearances.

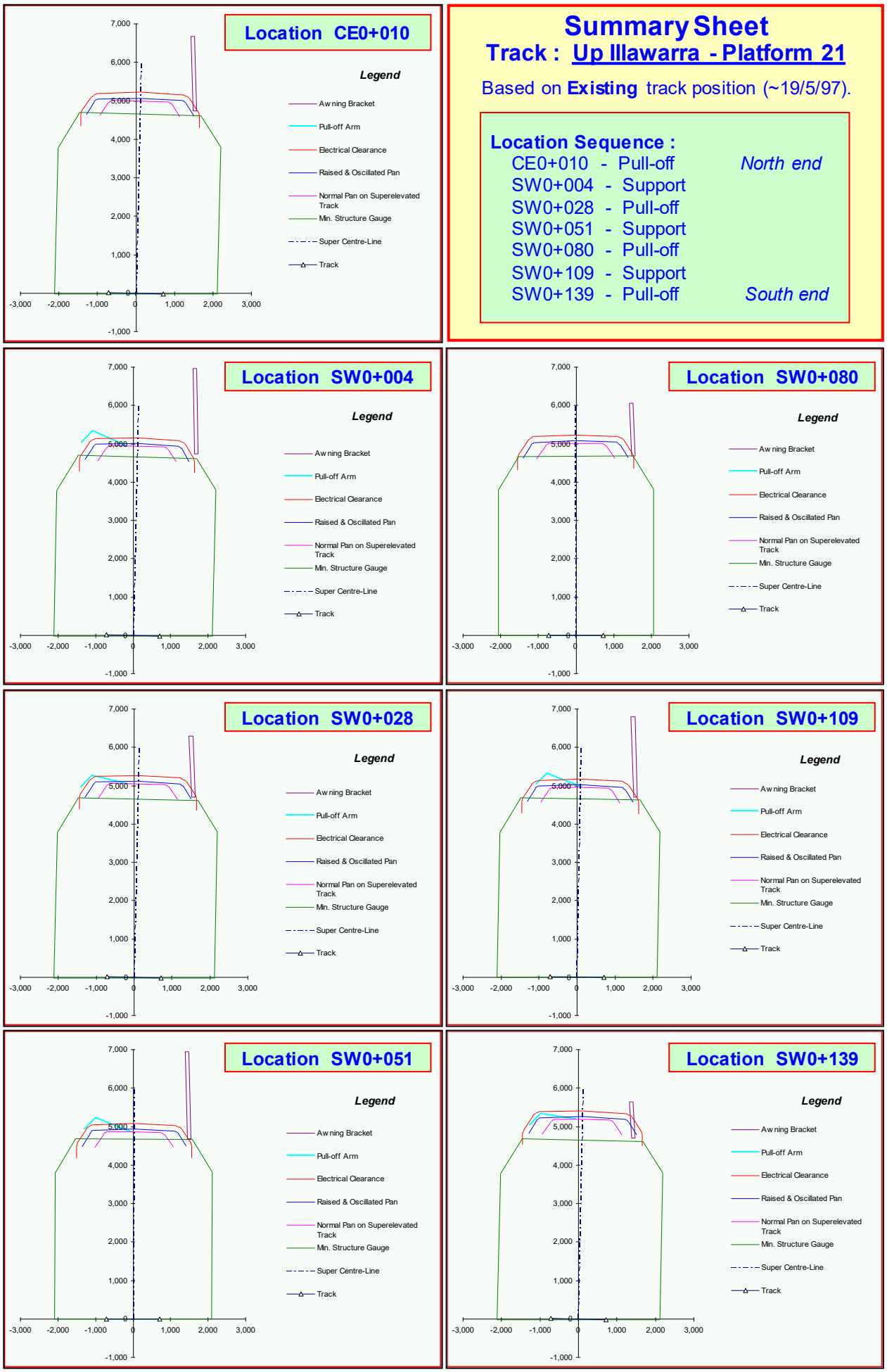


Figure 709 - Summary showing clearance infringements to Awnings

There were some improvements to be gained by regulating the (new) OHW, but the best solution involved removing all vertical panels (and associated brackets) from each platform, and this then gave plenty of clearance, ready for the future. And it was tastefully done.

Interestingly, it was one of the few times where it was the cold condition (not the hot condition) in the old fixed-anchored OHW system that gave the worst outcome (awning clearance problem). The catenary would rise at mid-bay under tighter (cold) tensions, bringing the contact wire up with it. And the contact height couldn't be lowered to help this situation because the mid-bay contact height would then be less than 4.57m under hot conditions (and thus not acceptable). It was a case of being caught between 2 limits.

It was this project that made me think of developing the "*PanGauge*" spreadsheet program for assessing pantograph clearances to surrounding objects. See *Section 6.3.2.4*. The strength of this program lies in the scaled diagram it produces (which is an excel *chart*), to diagrammatically represent the situation. This is obviously much easier to comprehend than just being presented with numbers. "*A picture is worth a thousand words …*".

6.4.6.2 Live OHW Over Platforms

Station platform level is typically about 1.2m above rail level, so any OHW conductors or other live equipment located above the platform will have a reduced height clearance relative to people standing on the platform. Refer to ESC 215, "Transit Space" standard for details about platforms (including definitions of "Standard Access" and "Level Access" levels above track).

These days, designing OHW with *live parts* extending over platforms is generally *not acceptable*. This includes the live boom of a Type 1A or 2A cantilever, with its live vertical member (to attach arm and set heel height) located above where people can stand on the platform.

Figure 710 - W&W Cantilever & Nose employed instead of Type 2A Cantilever (Kiama)

Instead, install some other arrangement that has a (dead) drop vertical located above the platform edge, with pull-off and its post type insulator mounted on its face – refer to *Figure 710* for example. The Type 2 cantilever installed here limits the amount of live equipment exposure, which is a far better outcome. Seeing the insulator probably helps too.

Also falling into this category are:

- Live registration ***cross spans*** – these older arrangements should have insulators installed close to platform edge to again limit the exposure to *live* equipment directly above the platform. These spans are generally no longer used above platforms.
- ***Anchor spans*** heading to anchor masts located on platforms. Anchor masts are generally not permitted on station platforms these days, partly for this reason.

However, there may be instances at platforms throughout the network where older OHW was not so well located in this regard, and these locations with live OHW may pose an elevated risk (so to speak).

6.4.6.3 OHW Structure Bonding at Platforms

OHW structures located on platforms need to be dealt with carefully when it comes to bonding the structures. Refer to Standard EP-12200001-SP, "Bonding of Overhead Wiring Structures to Rail".

In the distant past, virtually all OHW structures (portals or masts) throughout the electrified network were spark gapped to the track, so that if the primary insulation failed or the OHW structure somehow became alive at 1500V, this would cause the spark gap to short circuit and force sufficient fault current to flow to trip the associated substation / sectioning hut dc circuit breaker/s and isolate the fault and render the situation safer.

These days, spark gaps are only required at nominated places, including all structures on station platforms (as required by the policy in the above document).

On a platform, this policy can lead to many spark gaps being installed, and they all need to be periodically tested to ensure they are each intact (including that the spark gap is open circuit and the bonding wire connection to rail is intact).

Recent bonding schemes have endeavoured to minimise the number of spark gaps protecting a station and thus reduce the ongoing testing effort. This could be done by connecting a *group* of structures to a common spark gap with single bond to track. In this way there could be one or only a few bonding circuits at the station. In theory this should save time when testing.

The down side to this grouping method is when trying to find a fault, should the primary insulation fail, and the bonding scheme should consider this requirement also.

Including secondary insulation into the scheme seems an ideal way to tie all structures together to form a bonding circuit, and still have each individual structure able to be *earthed* and independent of the dc side of things. For example, refer to *Figure 479,* "Section 2. Secondary Insulation" / "Preferred" / "With Spark Gap".

Another recent aim is to provide appropriate *test points* at a convenient location, to more economically allow the routine testing of the bonding circuit/s. These test points should be able to discern if a spark gap is intact, and to check out any secondary insulation (e.g. record insulation resistance readings), etc. There should be enough documented indications to satisfy the tester of the ongoing integrity of the circuit/s.

Sometimes OHW portal legs need to penetrate the station roof. Where this happens, usually there is some form of insulation to electrically isolate the portal leg from the metallic roofing whilst also preventing water leakage to what's below. The portal itself may also need to have secondary insulation, to help prevent a shock if someone on the roof touches the structure at the time of faulty primary insulation.

Because there are many ways to deal with bonding structures at stations, in all cases, the actual bonding proposal needs to be designed and independently checked and signed by people with the engineering authority to do such work, and perform it to the current standards. And it needs to be implemented in the field as such (with test results recorded for confirmation).

6.4.6.4 OHW Structures Beyond Ends of Platforms

Requests were made within the Rail organisation in the 1990s to aim to avoid placing the legs of OHW structures immediately beyond the ends of platforms wherever this was deemed practical (I think the recommended clearance distance was about 10m to 20m at each end).

At that time the organisation was seriously considering extending more 8 car sets to become 10 cars (for transporting more people), in which case the nominated platforms would need to be extended. It was thought that having no OHW structures in the way of extending the platform would reduce the cost of making these changes at some time in the future.

This request was well intended, but unfortunately it is difficult to always keep the ends of platforms clear of OHW structures. This is because of bay length restrictions, and also the need to support and/or anchor other wires before reaching the platform, since there's to be no anchoring on platforms. (This is instead of having to carry the wires above the track through the platform area to anchor beyond the other end of the platform, which is not only costly and unsightly, it means more OHW to maintain into the future, and more that can go wrong.)

It's never an ideal world, but providing spare space at the ends of platforms for some future extension, where this can be reasonably achieved, could or should remain the aim for OHW designers. (That is, if the station hasn't already been extended.)

6.4.7 Line-Side Fencing

In order to reduce any stray dc current leakage through the earth and back to the substation, it is important to install "Insulation Panels" (at prescribed spacing) in series with any (otherwise continuous) metallic line-side fencing that runs parallel to the track corridor.

Refer to *Figure 711*, which shows 2 intermediate insulation panels, each supported by wooden posts, with air gaps in between and with no interconnecting metal between continuous metal fence and these panels. Signage (shown to the right) is important to help people understand the nature of what's trying to be achieved here.

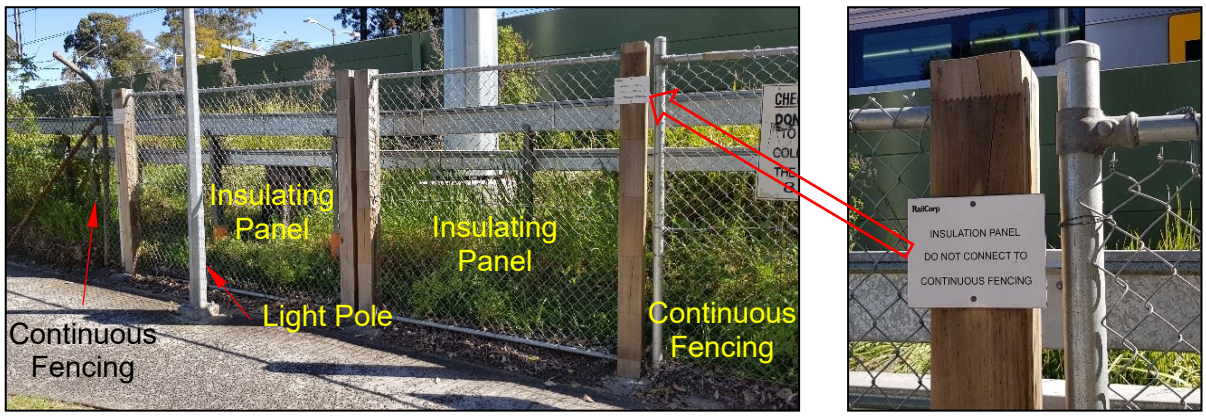


Figure 711 - Insulating Panels in line-side fencing with signage (Beecroft)

These panels effectively reduce any tendency for leakage currents to use the fencing as an alternate current path (instead of the track) back to the substation that supplies power via the OHW to the trains. The current can leak from the rails of the tracks themselves, or from OHW structures that have polluted insulators (for instance) that can leak current into the structure and earth.

I think the insulation panels are designed in a way that minimises hand-to-hand touch potential problems, should someone touch the continuous fence and the insulation panel at the same time.

Any nearby objects, such as the light pole in this diagram, need to be taken into account as possible touch potential points, with insulating panels installed to suit the situation (2 panels are needed here).

It may be of interest to note that *Figure 712* shows a highly corroded fence post with thick crusted rust scale localised at the ground line. The fence is not that old, and the galvanised steel post is installed next to a timber insulation post (and located quite near the photo in the previous Figure).

This steel post is connected to the steelwork of the overline bridge (in the backgound) which, although the OHW passing under it is unattached, does have several horizontal safety screens

which are apparently connected to a single spark-gap then to rail. If the spark gap shorts out, then it is possible for *rail volts* to cause vastly accelerated corrosion at the point where the post enters the ground, until the spark gap is renewed. The photo under and to the left was taken 5 months later, and the one to its right was taken a further 6 months later. The thick peeling crusts of rust show how rapidly this corrosion can advance. (The insulated timber post next to this post prevents any further transferred current and damage.)

Note:

> The horizontal safety screens may no longer be required (?) because of the more effective vertical screens ("bat wings") seen in the photo. Their removal, or otherwise disconnection from spark-gapped bonding circuit, may offer an improved outcome here in terms of minimising leakage currents.

A subsequent check confirmed that the spark gap in this situation was indeed short-circuited ("blown"). It has since been replaced with an alternate device.

This issue was discussed previously in *Section 3.12.0.5*, *To Bond or Not to Bond?* / *Example: Safety Screens on Overline Bridge*.

Same fence post 5 months later.
Rust layers forming.

Same fence post a further 6 months later.
Thick rust layers peeling away.

Figure 712 - Likely electrolysis corrosion at fence post & how quickly it advances

6.5 SIGNALS INTERFACE

To an outsider of the signalling discipline (such as me), there seems to be much mystery surrounding the signalling system. It obviously requires specialist knowledge and skills to properly understand, implement and operate it. The system requires knowledge of several aspects, including electrical, mechanical, pneumatics, the logics of train operations, etc. I readily admit I don't understand much of it, but there are some basics that relate in some way to the OHW system.

Because of the significant safety implications of signalling systems, the integrity of their various parts must not be jeopardised by the OHW system, so this interface can be crucial.

What follows are some of the more critical interface aspects (I think). However, if in doubt, consult the Signalling discipline for their advice.

6.5.1 Relative Positions of Signals & Open Overlaps

This issue is about preventing a situation of a train's pantograph stopping at a location that can cause the OHW contact wire to overheat and ultimately snap under its high mechanical tension. This can then disrupt train services for extended periods. It's covered in standard EP-08000004-SP, "Relative Positions of Signals and Airgaps". Probabilities have a part to play in this situation too.

This problem had led to the OHW failing at a few places throughout the network, at various times in the past, thus the need for the above Standard and its implementation in the field.

THE PROBLEM

OHW overlaps are an essential part of any OHW system, and over any particular track they occur at intervals of up to about 2km. Overlaps are formed where one OHW run must end (for various reasons) and then be taken over by the next OHW run. Refer to *Section 3.5*.

A significant risk occurs to the OHW if one of the train's several pantographs *stops moving* at a position that electrically bridges out both the in-running contact wires of different electrical sections, in either a ***feeding overlap*** or an ***open overlap*** (in the overlap bay). These parallel contact wires are only spaced about 300mm apart where they overlap. Refer to *Figure 713*.

The big problem here is that the carbon strips on a pantograph can allow the transfer of heavy electric current from one electrical section on to the next electrical section. If a train is in that next section, its heavy current may flow thought this contact-to-carbon strip-to-contact connection.

These carbon strips are not suitable for bridging the 2 sections for extended periods if the train is stationary. Recall that the current can be in the thousands of amps if the distant train is accelerating.

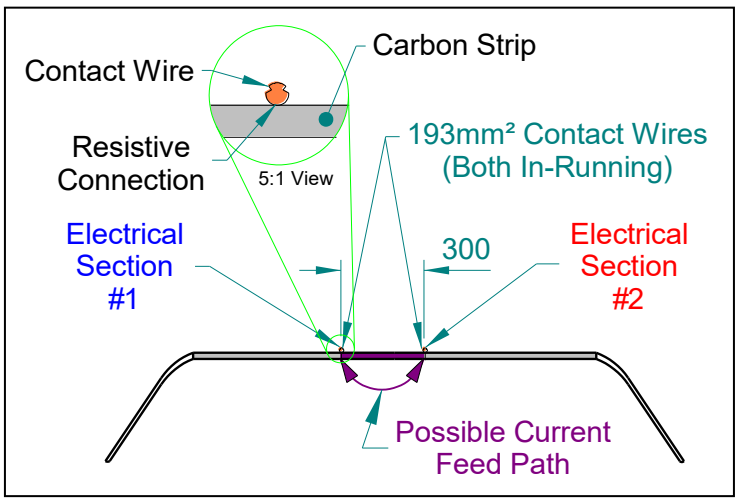


Figure 713 - Contact Wires of different Electrical Sections bridged by Pantograph

I think that even the stationary train that's bridging out the contact wires can be a concern. This train consumes current even when stationary: the relatively constant auxiliary power that feeds the train's onboard lighting, air-conditioning, compressors, etc., can be quite substantial

and may cause problems in this regard. Because there's 2 wires involved (with different source impedances), if there's a small vertical gap between one contact wire (that's just a bit higher than the other) and the pantograph, it can make momentary touch and break, and in doing so initiate arcing between this wire and pantograph. If the arc isn't extinguished quickly, it can cause damage here. But this may not be as problematic as the above situation.

The physical connection between copper contact wire and the carbon strip of the pantograph offers a relatively low, but in this case significant, resistive connection. This is in part because of the resistivity of the different materials, and also because the pressure applied to this connection can only be moderate. (The higher the copper/carbon connection force, the lower the resistance across the connection, which is desirable. But this force is actually the pantograph uplift force of about 130N total applied to 2 carbon strips on the pantograph head. Applying much more uplift force than this may lead to too much contact wire uplift, which will likely be extremely detrimental to the OHW system – read this as "uplifted pantograph damaging the OHW".)

There are likely 2 mechanisms at play here to cause damage to the contact wire:

- Any heavy current passing though this copper/carbon resistive connection will generate a local temperature rise in the copper contact wire (due to $I^2 \times R_{Connection}$). While the carbon may be able to tolerate higher temperatures without being damaged, unfortunately the hard-drawn copper contact wire is not so forgiving – it begins to anneal around 80°C or 90°C, then it starts to stretch as the heat-affected wire weakens while under full conductor tension.
- Also, very heavy current can cause some small arcing to develop between any imperfect copper/carbon connection, and the high local temperatures caused by this arcing can further accelerate the temperature rise, as well as locally damage the wire at this point.

The extent of vulnerable copper wire is probably within about 100mm on each side of the carbon strip/s – beyond this point the excellent heat conduction of copper will draw heat away into the rest of the copper contact wire, allowing it to cool and so limit any temperature rise.

In any case, the locally-overheated (annealed) copper wire can be permanently damaged, and weaken enough to stretch locally (within about 100mm of the carbon strip) under full applied conductor tension, until it snaps and drops onto the train. This is the adverse consequence of the heating risk.

This situation is much like the problem described in *Section 5.5.3.5*, *Pantograph Bridging an "Open" Section Insulator*.

THE SIGNAL RISK TO OHW

A signal at "red" will cause a train to stop in advance of the signal.

If the location of a signal is such that it causes a train to regularly stop with one of its several pantographs bridging a ***feeding overlap*** or an ***open overlap***, then this can lead to the above contact wire breakage problem.

VULNERABLE TYPES OF OVERLAPS

Not all overlaps pose a problem. Even the risky ones need to have reasonably heavy current to be drawn and for a certain amount of time whilst the offending pantograph bridges the overlap, for the contact wire to fail. So, probabilities come into play.

Some overlaps are *non-sectionable*, meaning you cannot electrically disconnect one run from the next at the overlap (the feeder jumpers are permanently installed, and the insulation does not allow for electrical sectioning). So, these overlaps always have the same electrical section on both sides, and a pantograph parked under and bridging it out will always be okay.

Some overlaps are *sectionable* and even *switched*, which means that one run *can* be disconnected (isolated) from the next at the overlap. Switched overlaps will have different electrical sections allocated to each side. A pantograph parked under a sectionable or switched overlap will generally not be of concern. This is because both sections are *normally tied together*, and if they are eventually isolated/switched open, then one of the sections would usually then be rail-connected (typically for maintaining the OHW, e.g. for "hands-on" inspections). Under this condition, a train should never venture into this overlap. But if it did, and one of its pantographs was parked under and bridged-out the overlap, under these circumstances it would trip the dccb protection (since the next section is rail-connected).

So, both of these types of overlaps are not affected by the location of signals, provided any isolation has its electrical section rail-connected – see below if not.

The overlaps that pose a real concern are *feeding overlaps* (at substations and sectioning huts) and *open overlaps*.

Feeding Overlaps

Here, it's relatively easy to isolate one electrical section from the next by opening a dc circuit breaker inside the substation or sectioning hut (remotely if needed). If the section is left isolated (and not rail-connected) and a train then ventures into the overlap and it stops (at a signal) with one of its pantographs bridging both electrical sections, then this can liven up the next section, and power any train that may happen to be in that next electrical section (which can cover quite a long distance). Even if it's stationary, the distant train's fairly constant total auxiliary current (for air conditioning, lighting, compressors, etc.) may transfer *through* the carbon strip/s of the offending pantograph from the live section, and this can cause the OHW to overheat and ultimately fail in a short time. But if that distant train then accelerates …

This problem can also result from circulating currents caused by the relative mix of various electrical resistance paths from substation to the OHW *through the bridged pantograph*.

Open Overlaps

These typically involve 2 totally independent electrical sections (and the overlap may not be close to any substation). But a train will get its current from whatever path is available.

A pantograph parked under this type of overlap will be more likely to cause the OHW to fail due to the current passing through the bridging pantograph. Again, it can be due to:

- Current demanded by a distant train delivered through this bridged pantograph, or
- Local disconnections and arcing from the offending pantograph to one of the 2 contact wires feeding the current. This can be due to only a small pantograph uplift force on one of the 2 wires, or due to a minute vertical gap from pantograph to the contact wire making intermittent contact and arcing.

Fortunately, there aren't many of these types of overlaps in the network, but they do exist and they need special treatment.

OPTIONS

Relocate the Signal

So, one important way of minimising the risk of this problem occurring is to locate the signals (that stop a train) a certain distance away from the feeding or open overlap, so that pantographs aren't likely to stop and bridge the overlap for extended periods. Refer to EP-08000004-SP for the specifics.

Install a Section Insulator

If the offending signal causing this risk cannot be moved, then the installation of a section insulator, at an appropriate place, should vastly reduce the likelihood of the 2 electrical sections being bridged. This same problem can also exist for pantographs parked under section insulators, where there will usually be 2 different electrical sections involved. This was covered in *Section 5.5.3.5*.

The big difference here is that the length of "overlap" (of 2 different electrical sections) where a pantograph can bridge both sections, is much shorter for an SI than for the typical overlap. In an *overlap*, the overlapping electrical sections can cover a distance of typically about 5m to 30m (bearing in mind that the upward pressure on a train's pantographs will lift the wires which will cause a longer overlap distance). Contrast this with a *section insulator* where the overlap length can be reduced down to as little as 180mm for Type 5 SI and 244mm for Type 6 SI. Refer to *Figure 404* and *Figure 405*.

In both cases, the width of a carbon strip plus distance between carbon pairs on a pantograph head, need to be added to the overlap length for the exact overlap *shorting distance*.

But what this means is that it's at least *about 10 times less likely* to bridge out an SI than an overlap. From here it's a game of probabilities, with the SI much less likely to cause the above problem – *but it can still happen*.

The only down side to this solution is that an SI typically requires much more maintenance. And there's a higher risk of failure, especially if the SI is installed on high speed track and begins to go out-of-alignment (its condition can then quickly deteriorate).

The other potential advantage to the SI is that the shorting of electrical sections *may* involve the copper *side runners*, which are not under any mechanical tension. So, if one or other the side runner fails, it is less likely to cause the substantial OHW damage of contact wire breakage (provided the damage is immediately observed and urgently fixed). Refer to *Section 3.6.0.5*, *Damage Due to Pantograph Bridging SI*.

6.5.2 Signal Sighting

Care must be exercised when designing OHW, to ensure that any new OHW support structure legs, and tension regulator weights, won't block the train driver's view of signals over any significant distance.

In the design process, when new (proposed) OHW structure locations are determined, but well before they're built, an "All Parties Walkthrough" is carried out, involving signals representatives. One of the main objectives is to try to identify any signal sighting issues so as to minimise the chance of signals being blocked over a distance. (Without the structures in place, it can be challenging to make this assessment, but this is the best time to do it.)

Figure 714 - OHW Not Interfering with Signal Sighting

If a new structure was installed, but subsequently deemed likely to block the driver's view of the signals over a critical distance, then it may need to be *relocated*. And so, the exercise is to prevent this potential waste (time and $) from happening. The situation of *Figure 714* is highly unlikely to cause problems in this regard (if only they were all like this!).

Various other OHW hardware, including cantilever pipes and pull-off arms, should be kept slender so that this equipment does not adversely block train drivers from seeing signals. This may be especially important in multi-track situations, where signals installed on signal cages are suspended under portal structures adjacent to relevant tracks. See *Figure 715* for instance. (The distance viewed along this Goulburn St Viaduct situation is more than 300m, and the photo only shows the 3 right-side tracks of the 6 main line tracks that cross it, so it's quite congested with all sorts of equipment).

Note also that there should not be any colours of reasonable size within the OHW system that could be misinterpreted as signals (colours red, yellow and green).

Figure 715 - Signal Cages located amongst OHW (new Regulated OHW on Goulburn St Viaduct c. 2006)

6.5.3 Anchor Wires Over Signals

In more recent times, there had apparently been concerns raised of situations where bare OHW anchor pennant wires were located directly over raised signal locations (with ladder access). Note that a newly installed signal location below existing OHW can cause this situation, as well as vice versa. In any case …

This situation was perceived as a potential safety issue, if signal maintainers climbing up the installed signal ladders could reach or come close to the anchor wires above. This is apparently even if these wires were at structure potential (i.e. with the anchor 1500V termination insulators located out closer to the track, deadening the wire above the signal).

I understand that insulating "tiger tail" covers (common in the electricity industry) were initially wrapped around the anchor wires in crucial locations, to help alleviate the perceived problem, as a temporary fix.

However, the best solution probably required the relocation of the anchor pennant wire to the next or previous mast (involving one more or one less bay respectively), provided the OHW design could accommodate this change.

6.5.4 Bonding to "Traction Rail"

When making any electrical connection to rail, a key requirement is to obtain signals advice on the method to best achieve this connection, so as to not interfere with the signalling system. Obviously this can have safety implications.

Common OHW design practice on any design drawing that asks for a rail connection (e.g. OHW switch arrangement), is to include a note such as "*Connection to rail of rail-connecting cable is to be performed by signalling section*". This puts the onus on the signalling section to provide the correct connection to suit their particular system at that location.

But as part of the OHW design, the signalling section should be consulted well in advance, to ensure that an appropriate form of rail connection can be made, so as to avoid unpleasant surprises later during construction.

Various types of connection to rail are possible, including direct connection to *traction rail*, connection to a local *impedance bond* which then connects to rail/s, etc. A track-side busbar for connecting to substation is shown in *Figure 716*. Refer also to *Figure 676* further back.

Figure 716 - Track-side Busbar

An *impedance bond* is a centre-tapped coil on an iron circuit that is connected between track rails, and with the centre-tap connected to substation negative or other tracks (as I understand it). This device has a high reactance impedance to the ac used in signalling systems, but has very low resistance to the dc of the OHW system. The purpose of this piece of equipment is to help to detect the presence of trains for the signalling system.

Also refer to *Section 3.12.0.5*, *Rail Connection*, to *Section 6.2.1.7*, *Insulated Rail Joints* and to *Section 6.2.1.15* for tie-in bonds.

Bonding to traction rail is an important interface, but further details of this specialist discipline are outside the scope of this document. Please refer to the Signals group or the current Standards for more details and up-to-date approaches.

6.6 THE SURROUNDINGS

6.6.1 Vegetation

Vegetation needs to remain clear of any OHW, for obvious reasons. Refer to *Figure 717* for an instance where a tree had decided to cover up the mast location number.

Fortunately, the OHW is mostly located above the track, and the track itself must be kept clear from any encroaching vegetation near passing trains – this activity is performed by the Civil discipline.

Anyway, requirements are stipulated in Standard EP-08000006-SP, "Vegetation Control Near 1500V DC Equipment (OHW)".

Figure 717 - Vegetation obscuring OHW Location Number

6.6.2 Aesthetics

Most people would agree that OHW is visually unattractive. A "necessary evil" maybe.

With this in mind, wherever it is practical to reduce the visual intrusion into people's lives, the OHW designer should strive to achieve the least aesthetically displeasing outcome. This is particularly relevant where there are distant vistas and water views of significance.

It makes sense to reduce the visual impact. And doing so also minimises the chance of the public complaining (although any change to what used to exist will likely be frowned upon).

The following are a few of the types of situations that may be pertinent here.

MINIMISE FLASHES FROM PANTOGRAPH ARCING

The sliding of pantographs along the underside of the contact wire can occasionally result in some arcing and consequent *bright flashes* with accompanying *loud noise* (if you're close to the action). This happens whenever there is a sudden disconnection while current is being delivered to the train (or received from the train when regenerative braking is applied).

The sparking flashes are most obvious during the night time. (Any accompanying loud arcing noise is less likely to be a problem, compared to the noise that the train makes on the track.)

These arc flashes can be most annoying to those people living in nearby houses or high-rise apartments, and particularly when these people are trying to sleep. The flashes can even be seen many kilometres away in direct vision, so the affected audience can be quite large.

If the flashes emanate from a fixed location each time, then this can be a constant, annoying distraction.

I include this issue under the "Aesthetics" heading because it can impact what people see (and may have to live with).

The ability of modern, lighter pantographs to more effectively trace the contact wire profile, helps to minimise any such interruptions and arcing. And the fact that there are 2 parallel carbon current-collecting strips on each pantograph, should also help reduce the instances of arcing.

But there is a limit to how much can be tolerated by the pantograph before arcing is likely to take place. And sometimes it cannot be avoided as it naturally takes place, such as when it powers through a section insulator (the second dot point below).

Situations that can result in arcing and bright flashes include:

- *Kinks* in the contact wire. (These can mostly be removed with appropriate tools.)
- *Section insulators*, where a train powers through from one electrical section to the next. (The resulting arc is extinguished when it rises up the arcing horns.)
- Various contact wire *fittings not aligned correctly*, which may pose an abrupt path for the pantograph, such as badly installed or misaligned contact full-splices, the side runners on a section insulator, etc.
- Parts of nearby OHW fittings that may go down to or just below the level of the bottom of the contact wire, and are therefore in the path of a pantograph. (Track superelevation can exacerbate this clearance problem.)
- When a train negotiates a facing turnout, the pantograph picks up the turnout contact wire and then eventually leaves the main line contact wire at the edge of the pantograph, potentially causing an arc at this point if the train is drawing a lot of current.

Even the speed of the train can sometimes contribute to the arcing outcome (and particularly the last pantograph on the consist, if OHW dynamics is a known problem).

AVOID "PICKET FENCE" OHW STRUCTURE LAYOUT

Yet another example of an undesirable visual outcome is if OHW structures are installed in some random order beside the track/s, giving the impression of either a chaotic layout or a "wall" of OHW structures –a so-called "picket fence" layout.

The ideal is to, *wherever practical*, have all OHW structures lined up laterally (for 2 or more tracks), and spaced uniformly along the track according to the *Structure Spacing Chart* – with bay lengths based on track radius.

Obviously a crossover may require additional masts for wiring that run, but these structures would normally be located only 2m or so from an existing main line structure.

VIEW OF OVERLAPS

There have been many examples where people living nearby wished to see less of the OHW infrastructure imposing on their wonderful view, including at Lavender Bay, Kiama, ….

Placing an *overlap* in someone's impressive view is a prime example of the problem. This typically results in twice the number of OHW conductors and twice the number of support & registration arrangements, installed on twice as many structures, all over 3 or 4 bays. Compare this with a single continuous OHW run which, although still in the view, is at least much less obtrusive.

Sometimes positive changes can be accommodated after the event (and at a price). But other times, it may not so easy to achieve.

Designing OHW with "minimisation" in mind can help avoid potential problems (and added costs later on) in these sensitive areas.

LOWER OHW STRUCTURES IN CERTAIN AREAS

One way of reducing the visual impact is to design the OHW and supporting structures as low as practical in these sensitive areas.

The old fixed-anchored OHW system generally relied on using very tall OHW support structures in order to obtain very long bays (and thus increase the virtual span number for improved catenary wire temperature / tension performance). Structure heights were sometimes in excess of 8.5m tall above track levels.

Changing to a regulated OHW system permitted these standard structure heights to be reduced down to much lower 7.5m height, which is a good outcome (thanks both to its much shallower catenary parabola and the fact that it doesn't droop any further when hot).

Also, for regulated OHW with its constant tighter tensions, the mast and/or portal bridge heights can be reduced from this standard 7.5m to something like 7m or even less, especially where slightly shorter bays exist (resulting in even less catenary sag in the bay).

Depending on the situation, even a small amount of structure lowering, of 500mm or more, can be effective at reducing the visual impact over several successive structure locations. In this way, the OHW becomes more compactly tied to the track/s being serviced (albeit with a little less vertical room to allow for subsequent alterations, errors, etc.).

Another thing is to avoid installing auxiliary feeders well above the existing OHW in visually sensitive areas.

Example:

Figure 718 shows a photo taken from a frequently used footpath and grassed picnic area located near Waverton Station (next to Sydney Harbour), with some pretty spectacular views of Sydney in the background.

It's disappointing to see areas that had been deliberately designed with lowered OHW and structures down to 7m height – *to reduce visual impact* – only to have a single, high auxiliary feeder installed much later on, from gallows fittings projected way above these lowered portal structures.

The photo was taken in 2018, apparently soon after a new single auxiliary feeder (A/F) was installed. Unfortunately, the A/F cuts right across and spoils the distant views. Two structures to the right of the portal in this picture had the A/F wire *suspended under the portal bridges* for several further bays heading towards Waverton Station (to the right), and this approach should have ideally been continued through here as well, rather than projecting a series of tall gallows fittings well *above* the portal bridge as shown. One would hope there was a good reason for doing this (?).

To give an appreciation of the relative heights of the new structures, *Figure 719* is a view from the harbour in the opposite direction. It shows the older tall, brown structures at the time they were progressively being substituted by the new, shorter ones. The picture of *Figure 718* was taken at a position roughly below the text in this photo. Note that the shiny galvanising on the new structures soon dulls to grey as the zinc coating oxidises, and they then blend in better with the surroundings and don't draw much attention to the eye.

The shorter structures became a practical option here because of the tight track curves requiring shorter bay lengths, but more significantly, the constant higher catenary tensions of a regulated OHW system result in much shallower catenary sags.

Sometimes aesthetic outcomes are defined in the project scope. But if they're not, then the designer and checker still need to be aware of any situations that may be visually sensitive, and remove themselves from "auto-pilot" mode when designing the OHW in these

surroundings, to strive for a better aesthetic outcome. An early site visit is essential for identifying any such visually sensitive areas.

Figure 718 - Additional lone Auxiliary Feeder spoiling the view

Figure 719 - New lowered OHW Structures replacing older taller Structures (c. 2007)

Even the solid thickness of tension regulator weight stacks, often installed side-by-side in pairs, can be visually obtrusive in certain circumstances.

Unfortunately, once the OHW is installed, it becomes difficult to obtain additional money and motivation to improve the aesthetic situation (unless the locals revolt and involve the media, which seems to be happening more often these days).

I know I'm probably guilty of designing OHW without giving much appreciation to the surroundings. I guess such awareness, if it happens, comes with age as you begin to slow down and start to "smell the roses" …

The above "Aesthetic" issues are just a few things to seriously consider during the early design phase, and especially when confronted with any visually sensitive areas in the project.

But some of these issues also need to be understood during construction of the OHW, and later on during its maintenance. Of particular importance is preventing or minimising, as far as is practical, any chance of pantograph arcing and its accompanying bright flashes. Otherwise, watch the complaints roll in …

7 OHW Documentation

What follows is a brief summary of the types of documents typically produced in any new OHW design for a particular project, and thus the information that should be available for subsequent changes to OHW design.

The underlying requirement of this documentation is *clear communication* – mostly from the design phase, to allow its construction without ambiguity.

The design needs to also reflect what was actually built ("as-built"), including any local deviations from the design (which should be signed off by design staff anyway). Refer *Section 2.5.12*, *Application of Tolerances*.

7.1 OHW FITTINGS

A system of identifying the various standard OHW fittings, assemblies and arrangements has been in place in the NSW Railways since initial electrification in the early 1920s, and it relies on the establishment and control of unique *Fitting Numbers*.

The fitting numbers are based on a numbering system of the format:

" **XXX / YY** ".

For example, a "954/52" fitting is a 1.2m long pull-off arm, as described in its associated fitting drawing D/80580 Sheet 1 (showing fabrication details).

Other examples of fitting numbers are:

- 61/2 – a contact swivel clamp that attaches to the end of the above pull-off arm,
- 453/13 – a disc insulator, and
- 511/32 – a 16mm diameter stainless steel pin.

Fitting numbers have also sometimes been given to arrangements (assemblies), for example:

- 49/1 – is a contact wear strip arrangement, and
- 510/8 – is a Type 6 section insulator for installation on twin contact wires.

Fitting numbers have been adopted mostly as a matter of convenience for easy reference (especially when people are familiar with the equipment, as happens over time).

Note that fitting numbers with a "T" prefix indicates a Transmission Line fitting (HV Aerial Line), and some of these have been used in the OHW system.

Example:

- T11/7 – is a copper thimble used to help terminate a copper span wire onto a stainless steel pin of an insulator or similar hardware.

The index for all OHW Fitting Numbers is contained in the 4 old "Brown Books", but hopefully the information has been transferred to a database by now(?) and kept up to date. These books nominated the fitting number, physical description of the fitting and importantly the associated drawing number that shows the details of the fitting.

All drawings are (or at least were until recent times) kept and maintained in the Railway's own Engineering Document Management System (EDMS). This system includes infrastructure drawings and documents for all disciplines (Signals, Civil, Track, Electrical, etc.) and covers the entire state of New South Wales. *Section 7.4* has a little bit more to say on EDMS.

For more information on the Fitting Number system, refer to *Section 5.1.6*.

7.2 DRAWING RECORDS

Before OHW can be installed, the various OHW runs need to be designed to suit the project specifics for that area, operational requirements, etc.

The physical description of the OHW system to be built in the field is provided by the following types of design drawing records (listed in order of typical sequence):

1. 1500V Electrical Sectioning Diagram (normally an input to the design process)
2. Tension Length Diagram
3. OHW Layouts
4. Conductor Profiles
5. Cross-Sections
6. Overline Bridge Arrangements
7. Anchor Arrangements (including a "WeightSet" sheet for each weight tensioner).
8. Switch & Feeding Arrangements
9. Bonding Arrangements

In addition to the above, if the project has some unique OHW conductor configuration, then the following would likely be also required (to be signed-off by Standards, and probably needed before the project proceeds and any of the above documents are produced):

10. New Data Sheets (recording the proposed conductor configuration)
11. New Support & Registration Standard Arrangements
12. Other New Standard Arrangements that may also be needed

Note that there may be other types of OHW design drawings, but the above list is typical for a new OHW project.

With all design drawings, time spent during design to *get it right* will pay huge dividends in terms of minimising any wasted effort during construction, when closedowns to build OHW are normally of very limited duration (usually closedowns occur on weekends). This warrants providing a design that is clear on intent and includes any checks or measurements to be conducted at the end to confirm that the built arrangement is within tolerance and is fit for service.

More information on each type of drawing is described below.

7.2.1 1500V Electrical Sectioning Diagram

This drawing is normally produced in colour and shows the proposed Electrical Sectioning that the OHW design is to deliver. It is usually provided as a linear map, sometimes with only rough scaling (enough to give an appreciation of the area).

Different colours represent the different electrical sections that are needed to provide the necessary electrical protection and isolations for future maintenance work, etc.

It should contain the signatures of all key stakeholders, to acknowledge agreement and to allow the OHW design to proceed with reduced risk of any future changes (surprises). If any of the other documentation is produced prior its signing, there is a real risk of wasted time, effort and associated costs, since changes are quite likely to be made before final sign-off.

Refer to *Figure 721* for an example of an Electrical Sectioning Diagram (for Epping).

7.2.2 Tension Length Diagram

This diagram shows all the proposed wire runs on a linear map of the area. It shows how the designer intends to run the various lengths of wires in order to satisfy the feeding, switching and electrical sectioning of the above diagram, and also based on the physical limitations of an OHW system (particularly the maximum permissible conductor tension lengths).

It shows the start and end locations and the resulting run lengths (in metres) of the various wire runs planned for a new design. It should show the Sydney-end and country-end anchors and any fixed mid-point anchors (for regulated OHW), and the type of anchors at each location.

This diagram is generally not to scale, but should give the "big picture" of the proposed outcome, in terms of how the runs interact with each other (including crossovers, sidings, etc.), and with the surrounding environment. So, fixed salient features such as stations, bridges, tunnels, substations and sectioning huts, etc. should be included.

REGULATED OHW

For a regulated tension OHW system, there is:

- A "Moving" end (tension regulator, e.g. weights) at one or both ends of the wire run. Symbol is "**M**" in a circle.

To help control the movement of the weights, then either of the following 2 anchors are also required for the wire run.

- A "Fixed" end with simple fixed anchor. Symbol is "**F**" in a square box. Or
- A "Fixed Mid-Point" located between 2 Moving anchors (one at each end). Symbol is "**FMP**" in a rectangular box.

In a regulated tension system, the tension loss figure should be shown at any fixed anchor and any fixed mid-point anchor locations. (The full tension is delivered by the tension regulator, so it is not relevant to show this information at the Moving end/s of the run.)

FIXED-ANCHORED OHW

For a fixed-anchored OHW system, the Sydney-end and country-end of the wire run have a simple "fixed anchor". Symbol is "**F/A**" in a rectangular box (F/A is meant to distinguish it from a fixed anchor in a regulated OHW system – see above).

If the catenary run and contact wire run separates (as they unfortunately used to do in the old days), then each anchor needs to be shown along with the name of the relevant conductor (catenary or contact wire). Note that this approach of allowing the catenary and contact wires to part from each other is no longer acceptable in future OHW work.

Refer to *Figure 722* for an example of a Tension Length Diagram (at Chatswood). Also refer to Standard EP-08000010-SP, "Overhead Wiring Layouts – Requirements And Symbology".

7.2.3 OHW Layouts

These drawings are a scaled *plan view* of the proposed runs of OHW. The scale is normally 1:500 and the details are usually drawn on a large A1 size drawing these days. Some older OHW layouts used a scale as small as 1:1,000 (some are even smaller) which made it very difficult to interpret the configuration of the various OHW runs correctly – anchor to anchor (especially where crossovers and turnouts existed).

Note: These older layouts relied heavily on associated OHW profile drawings for an understanding of the various wire runs.

The precise location of the runs of OHW on the scaled drawing allows the designer to determine things such as conductor radial loads, contact wire blowout, etc. which are all crucial to achieve an accurate OHW design, that can then be built and reliably operated.

Layouts normally include showing and naming local features, such as roads, stations, bridges, etc., which will allow future maintenance staff to know where to go to when needed, and this information is especially useful in emergencies.

Refer to Standard EP-08000010-SP, "Overhead Wiring Layouts – Requirements and Symbology" for the format of details required. See also *Figure 720* for some typical symbology used on a recent local project.

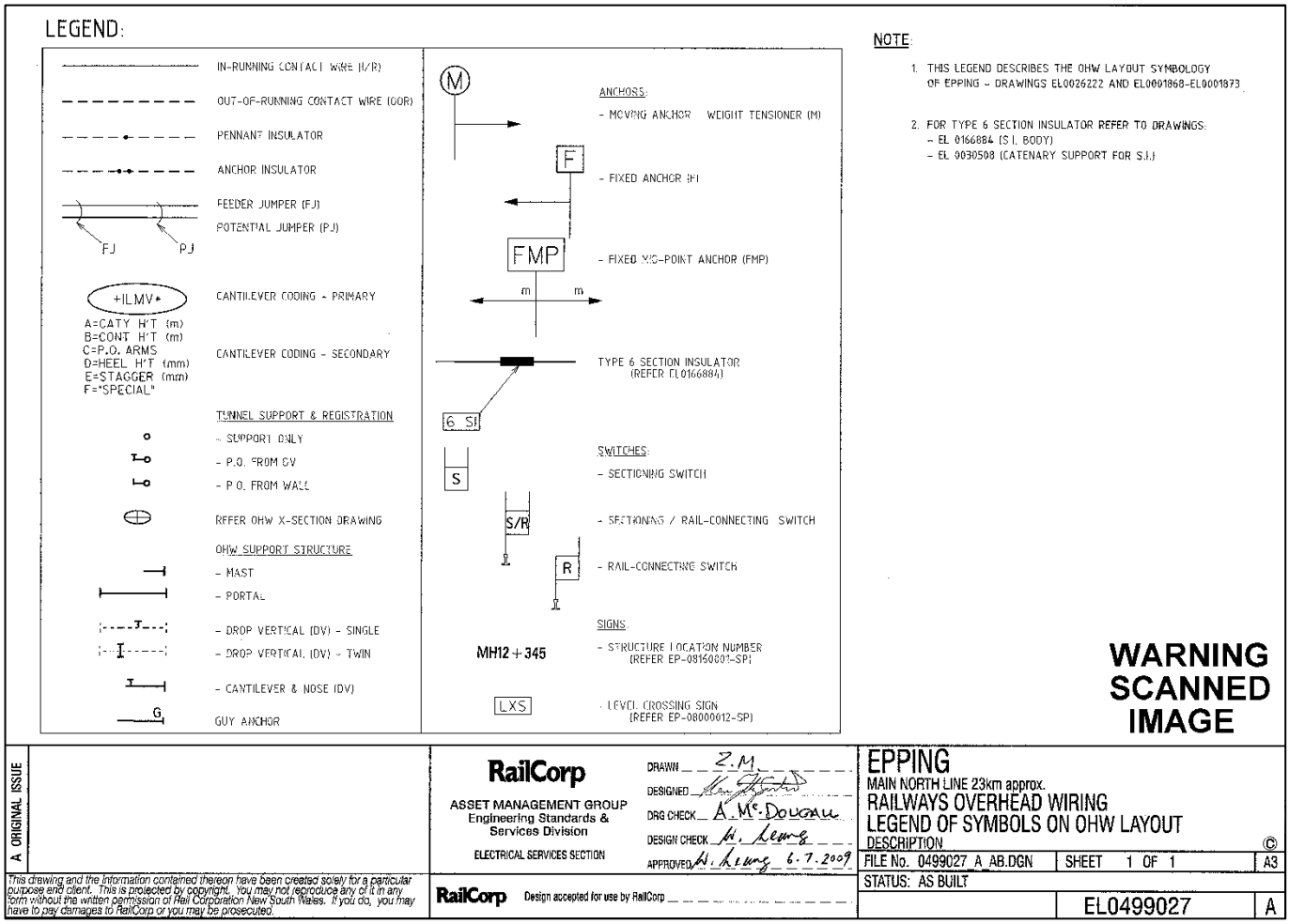


Figure 720 - OHW Symbology on Layouts

Example:

Chatswood / RES – see *Figure 677* and *Figure 679*.

Refer to *Figure 723* for an example of an OHW Layout drawing (at Epping).

See also *Section 10.1*.

7.2.4 OHW Conductor Profiles

These drawings are required if the OHW passes under an overline bridge, tunnel or other overhead structure that causes reduced clearances above (or below) the OHW conductors. Their purpose is twofold:

- To show these critical clearances clearly on the drawing, to confirm to the designer that the design will meet the required minimum statutory electrical clearances.
- To allow the constructor to confirm that the shown clearances (above) have been met when the OHW has been erected. This is a crucial task. The actual clearances should be measured in field, documented and handed over to the District for confirmation of suitability and for subsequent maintenance.

The profiles are usually drawn at a distorted scale of 1:50 vertically and 1:500 horizontally. This vertical exaggeration helps measure and emphasise (show) any critical vertical clearances. (Refer to *Figure 500* for a better appreciation of this approach).

Refer to *Figure 724* for an example of an OHW Profile drawing (at Chatswood).

See also *Section 10.1*.

7.2.5 Cross-Sections

The various *cantilever standard arrangements* were developed to help expedite design as well as construction activities. However, they cannot always accurately describe *all* situations for supporting and registering OHW. So, OHW cross-sections are needed when the various cantilever standard arrangements do not fully describe what's needed at each location.

Cross-section drawings document exactly what the designer wants the constructor to build, and include details such as component fitting numbers, conductor heights, staggers, etc.

They typically contain a bill of materials (BOM), which helps describe the various parts needed, and can aid construction (early on) to purchase the various parts and in the required quantities.

Sometimes, complex situations can benefit from the drawing of a cross-section, even if the Cantilever Coding describes all that's needed (a picture's worth a thousand words …).

Refer to *Figure 725* for an example of an OHW Cross-Section drawing (at Chatswood).

See also *Section 10.1*.

7.2.6 Bridge Arrangements

Overline bridges are mostly annoying things – it seems each one is different when it comes to supporting & registering the OHW from the bridge structure in some fashion.

The bridge arrangements needed for describing the support & registration configuration are like cross-sections (above), but they can contain other elements such as the *bonding* requirements.

Refer to *Figure 726* for an example of a Bridge Arrangement drawing (at Chatswood).

See also *Section 10.1*.

7.2.7 Anchor Arrangements (Non-Standard)

These arrangement drawings are only required if the existing standard anchor arrangement drawings are unsatisfactory or require modifications to some degree – the documentation of the changes are needed for accurate construction and for future reference.

If important enough, the drawing/s can become a "standard arrangement" so as to help any future project in the same situation.

The development of such a new drawing should be encouraged, but it requires a higher level of sign-off (e.g. Principal Electrical Standards Engineer).

7.2.8 Switch & Feeding Arrangements

Switching and feeding arrangements are combined here because they can use common elements – HV cables and bare aerial wires. Switching is usually a local thing from switch to OHW (although switches can also exist at substations and sectioning huts). Feeding is from a substation or sectioning hut to the OHW.

In order to accurately build any switch or feeding arrangement, a drawing needs to detail exactly how this is to be achieved, as the arrangement can be quite complex. But the designer needs to be in control here.

Because of the amount of detail involved, these drawings often take a long time to develop and get right for sign-off as "approved for construction".

These drawings are crucial as they show precisely how the designer expects the builder to install the switches and/or feeding cables and/or aerial feeder wires to the OHW conductors. (Both the catenary and contact wires need to be fed at each connection to the OHW.)

The following are of particular importance:

- Showing how a switch is connected (mounted) to the mast,
- Detailing the brackets and other hardware needed to support the various cables from switch or substation / sectioning hut, out to the "cable-to-aerial feeding point", for subsequent aerial connection to the OHW. These brackets (spaced up to 1m apart) solidly hold the cables in place in case of a sudden heavy fault current with accompanying large repelling or attractive dynamic forces on the cables.
- Showing the various critical *electrical clearances* and how they are to be met. These clearances should be clearly shown so that the constructor can confirm the final measured clearances. Note that regulated OHW, and wind gusts, both add a dynamic element to the design, and this needs to be taken into account by setting the fittings and clearances appropriately.
- Showing any *surge protection* to protect cables from lightning surges.
- Showing any *earthing* and/or *bonding* requirements for implementation and recording.

Refer to examples shown in *Figure 727* (Switching Arrangement at Central) and *Figure 728* (Feeding Arrangement at Central).

See also *Section 10.2*.

7.2.9 Bonding Arrangements

These special drawings need to show (explain) how the OHW fittings, safety screens, etc. need to bonded to make the situation *safe* and/or minimise the chance of *electrolysis corrosion* of local services. This is sometimes a balancing act with various risks.

They are likely to include "cross-sections" taken at particular locations where bonding connections need to be made to steelwork, and show bonding cable route information to the spark gap location and connection to track (the connection to track is normally performed by signals staff).

Refer to *Section 3.12* for some additional information. Also refer to *Figure 465* for a simple bonding arrangement drawing, although they can get much more complex than this.

7.2.10 New Data Sheets

Data sheets help explain the characteristic of a particular wire system or other aspect of the OHW.

If a new OHW system is proposed, then relevant drawings need to be made and signed off (by the Principal Electrical Standards Engineer) to become valid for reference and use in Sydney's OHW system.

Data sheets include:

- OHW Structure Spacing Chart.
- Temperature/Tension Charts (even for regulated OHW systems, these are usually required for when the wire is initially set up as fixed-anchored before the weights are released). Having these charts is particularly necessary if a Temperature/Tension Calculation program is not available in the field when the information needs calculating on the day (at that temperature) for constructing the OHW. And any computer program used for this purpose needs to be *validated* for that new wire system.

7.2.11 New Standard Arrangements

Any time that the normal standard arrangements do not suit a particular project, and a new arrangement has instead needed to be developed, if it could also be applied in other projects (in future), serious consideration should be given to converting it into a new standard arrangement drawing (or drawings).

This will require checking the mechanical loadings of course, and also prototyping, performing a failure modes analysis (FMECA). And it needs to also get sign-off at a high level (Principal Electrical Standards Engineer).

The big benefit of this approach is that the new arrangement may be used in other projects, should the same need arise in future, with potentially large savings.

(Unfortunately however, these days there's little incentive to go down this path, which is unfortunate and such a pity.)

7.3 CALCULATIONS & DOCUMENTATION

There are a number of documents that typically support the above drawings, including:

- ***Loading diagrams*** – for showing the proposed maximum loadings on an OHW structure to be designed, or loading onto existing structure (masts and portals, overline bridges, tunnels, etc.). Information is issued to Civil Design.
- ***Drop vertical length & position tables*** – for sizing and locating all drop vertical on a portal. Information is issued to Civil Design.
- ***Dropper calculations*** – for showing a schedule of the droppers for each bay in each wire run.
- ***Support & registration calculations:***
  CCalcs – for Mark-2 cantilevers,
  PO-CALCs – for pull-offs,
  TCalcs – for Mk-2 tunnel cantilevers.
- ***S&R schedules*** – for other tunnel situations, etc. (which perform much the same task as CCalcs). This should give all the necessary information to install each site-specific S&R arrangement at each location.
- ***Catenary sag calculations*** – for determining suitability of heights, bay lengths, etc.
- ***Temperature/Tension calculations*** – for checking the catenary and contact wire tension suitability under hot, normal and cold temperatures.
- ***"MinCont" calculations*** – which confirm the contact wire will remain above the minimum height under hot conditions (for fixed-anchored OHW systems only).
- ***"PanGauge" clearance checks*** – to ensure the pantograph doesn't come too close to nearby objects (drop verticals, station awnings, bridge steelwork, etc.)
- ***Overlap calculations*** – to confirm the design of suitable overlaps, typically using the "Overlap.xls" spreadsheet program.
- Etc.

Each OHW project should include all relevant information (as above) to support and confirm suitability of the OHW design produced (and be verified as required during the "design check" process). Information should be included in the Job Folder for that project.

See *Section 8.3* for a list of available software tools to help perform the necessary calculations.

7.4 DRAWING SIZES

Prior to the 1990s, drawing numbers were prefixed with a letter, for example "D/80580", which represented the drawing size as detailed below (shown generally in diminishing size):

- A – the biggest drawing
- K – Similar to the A size above
- B
- C
- D – similar to A3 size,
- E
- EE (which is like an A3 drawing in landscape, but twice as wide, and usually associated with an old OHW bridge arrangement drawing).
- F

The drawing number could include 1 or a multitude of sub-sheet numbers, starting from 1, and sometimes included a letter, e.g. "D/87654 Sheet 3b".

During the 1990s, Sydney's railway plan room transferred all drawings over to "EDMS" (Engineering Document Management System). This required that all *Electrical* drawings start with the prefix "EL", followed by a 7 digit number, for example the drawing D/80580 Sheet 1 has the EDMS number EL 0017017.

Each drawing had a separate *unique number*, which meant you could no longer have several sheets of the same drawing number (which used to be convenient for OHW Layout series, for instance, where you could have the one drawing number and 100 or so sequential sheets associated with that drawing number). With the new drawing number scheme, the best you could hope for was that these new "EL" numbers be *sequential* (but unfortunately this was not always guaranteed). Civil and Track design drawings have the prefix "CV".

Since the 1980s, Sydney's railway has used the following standard metric sheet sizes:

- A0 – 841 × 1,189mm – sometimes used for OHW Layouts
- A1 – 594 × 841mm – mostly used for OHW Layouts these days
- A2 – 420 × 594mm – typically used for general arrangement drawings
- A3 – 297 × 420mm – used for detailing parts and for OHW Cross-Sections, etc.
- A4 – 210 × 297mm – used for data sheets, etc.

One of the big benefits with these latter sizes is that each drawing size is exactly twice the size of the next smaller size (rotated 90°) , which is convenient for folding to a smaller standard size. For example, an A2 size can be folded once to become A3 size, then folded again to become exactly A4 size, then poked inside an A4 plastic sleeve and attached to the Job Folder (which was a good way to keep the original *signed* drawings).

8 Standards & Other Information

This chapter identifies some of the *Standards* that must be adhered to (as at 2014) when dealing with the OHW system: when designing and constructing the OHW, and when maintaining or operating it. Check for more recent standards (especially those using an update numbering system), as they must take precedence over those listed here.

It also provides a list of the typical *OHW Equipment* (which point to the multitude of *Components*) used these days (2014) to build OHW. Again, check for updates.

Various *OHW Tools* are also listed – these are computer programs mostly used for design work to help speed up the design process, and provide a high degree of accuracy and consistency, etc.

In addition, I thought it may be useful to include a section on *Unit Conversions*, to help the reader swap from the *metric system* used throughout this document (Australia's standard measure) over to the *imperial system* and vice versa.

8.1 STANDARDS

Table 53 is a list of the standards relating the 1500V OHW, as of time of the start of rewriting this document – 2014.

This list will change over time, so it would be prudent to check for additional standards as well as for current revisions prior to using any information from these standards or indeed from this document. Indeed, the naming convention for the standards may also change.

Publication No.	Title
EP 08 00 00 01 SP	Overhead Wiring Standards for the Electrification of New Routes
EP 08 00 00 02 SP	Overhead Wiring Maintenance Standards
EP 08 00 00 03 SP	Overhead Wiring Base Safety and Operating Standards
EP 08 00 00 04 SP	Relative Positions of Signals and Airgaps
EP 08 00 00 06 SP	Vegetation Control Near 1500V DC Equipment OHW Policy
EP 08 00 00 07 SP	Safety Screens for Bridges over 1500V OHW Equipment
EP 08 00 00 08 SP *	Crossover and Turnout OHW Geometry
EP 08 00 00 10 SP	Overhead Wiring Layouts – Requirements and Symbology
EP 08 00 00 12 SP	Level Crossings – OHW Clearance Requirements
EP 08 00 00 13 SP	Overhead Wiring Fittings and Materials
EP 08 00 00 14 SP	Services Erected Above Overhead Wiring
EP 08 00 00 15 SP	Overhead Wiring Construction and Commissioning
EP 08 00 00 16 SP	Designations of Overhead Wiring Conductor Systems
EP 08 00 00 17 SP	Overhead Wiring Conductor System Selection Criteria
EP 08 00 00 19 SP	Performance Specification for OHW Post Insulator Units
EP 08 00 00 20 SP	Performance Specification for OHW String Insulator Set
EP 08 00 00 21 SP	Insulator Type Tests – DC Power Arc Withstanding
EP 08 00 00 24 SP *	Contact Wire
EP 08 16 00 01 SP	Labels for OHW Structures
EP 08 16 00 02 SP	Safety Barriers for OHW Structures
EP 12 10 00 13 SP	1500 V Traction System Earthing
EP 12 20 00 01 SP	Bonding of Overhead Wiring Structures to Rail
EP 12 30 00 01 SP	Electrolysis from Stray DC Current

Note: * – Temporarily withdrawn – to be reinstated.

Table 53 - Typical Standards Publications Relating to OHW

Note that the first 3 standards were initially written and signed off at the same time in 1994, and the urgent request for these came from the top of State Rail at that time. (The same request was directed to the other Engineering Standards areas of Electrical, and to Signals, Civil and Track.) They were to describe:

1. The standard requirements for any ***new OHW equipment*** (and ideally applied to any modified equipment too), viz. EP 08 00 00 01 ST.
2. The ***minimum requirements of any OHW equipment***. Urgent steps needed to be taken to correct the condition of the asset, e.g. parts worn below a certain value, viz. EP 08 00 00 02 ST.
3. The ***base line conditions of any OHW equipment***. If the condition of equipment was this bad, then it was sufficient reason to "stop trains" to correct the situation. This had both safety and operational criteria, viz. EP 08 00 00 03 ST.

It should be pointed out that the suffix "ST" (Standard) was changed to "SP" (Specification), which was thought (at a later time), by some, to better describe the purpose of the document.

The remaining standards were progressively developed after the first 3 above were signed off, in order to try to cover the entire scope of the OHW system more fully.

8.2 OHW Equipment List

Below is a listing of the "Standard OHW Arrangements for New Electrification", including the corresponding drawing numbers (old and new).

Note that this list was current in 2014, so is likely to have been updated many times since, as things changed. (Or maybe not?)

Before using any information, please check for an updated list (which may or may not be available on the internet).

RailCorp - Standard OHW Arrangements for New Electrification

Publication Date : 14/02/2013 = Updated

Note: * This is a list of current RailCorp OHW Standard Arrangement drawings. It is not an exhaustive list, but incudes the majority of the common arrangements used in Electrification Projects.
* The relevance of each Standard Arrangement for a Project is to be assessed by the OHW designer.
* This List provides the current Drawing Amendment at date of publication.

Category	Category	Aspect	Drawing Description	Drawing No.	Sheet No.	EDMS Number	Amendment	Document Title
1. Conductors	Droppers					EL BLANK		
		New Standard Dropper - Single & Twin Contacts	New Droppers - Arrangement Mapping	EL 0106184	-	EL 0106184	A	GENERAL RAILWAYS OVERHEAD WIRING STANDARD DROPPER - SINGLE & TWIN CONTACTS ARRANGEMENTS
		Standard Droppers	Standard Dropper - Arrangement	EL 0254113	-	EL 0254113	C	GENERAL RAILWAYS OVERHEAD WIRING STANDARD DROPPER - SINGLE CONTACT ARRANGEMENT
			Standard Lower Loop - Sub-Assembly	EL 0232898	-	EL 0232898	D	GENERAL RAILWAYS OVERHEAD WIRING LOWER LOOP FOR STANDARD DROPPER SUB - ASSEMBLY
			Standard Short Dropper - Arrangement	EL 0232899	-	EL 0232899	D	GENERAL RAILWAYS OVERHEAD WIRING SHORT DROPPER - SINGLE CONTACT ARRANGEMENT
		Tunnel Droppers (Single Catenary / Twin Contact)	Twin Contact (Delrin Bar) Dropper - Arrangement	EL 0474340	-	EL 0474340	C	GENERAL RAILWAYS OVERHEAD WIRING STANDARD DROPPER - TWIN CONTACT ARRANGEMENT
			Twin Contact (Delrin Bar) Lower Loop - Sub-Assembly	EL 0254305	-	EL 0254305	C	GENERAL RAILWAYS OVERHEAD WIRING LOWER LOOP FOR TWIN CONTACT DROPPER SUB ASSEMBLY
			Twin Contact (Delrin Bar) Short Dropper	EL 0232901	-	EL 0232901	D	GENERAL RAILWAYS OVERHEAD WIRING SHORT DROPPER TWIN CONTACT ARRANGEMENT
(to be phased out) -->		Single Contact	Single Contact System Dropper Arrangement	D/80649	2	EL 0017103	A	RAILWAYS OVERHEAD WIRING SINGLE CONTACT SYSTEM DROPPER ARRANGEMENT
(to be phased out) -->		Twin Contact - 50mm Separation	Twin Contact System Dropper Arrangement	D/80589	2	EL 0017034	A	RAILWAYS OVERHEAD WIRING TWIN CONTACT SYSTEM DROPPER ARRANGEMENT
(to be phased out) -->			Twin Contact Dropper Lower Loop	D/80590	-	EL 0017035	C	RAILWAYS OVERHEAD WIRING; TWIN CONTACT DROPPER LOWER LOOP
(to be phased out) -->	* Restricted Dropper	Single Contact	510 mm^2 Copper Catenary Restricted Short Droppers Arrangement	E/73734	-	EL 0034396	C	RAILWAYS OVERHEAD WIRING; 0.8SQ' COPPER CATENARY RESTRICTED SHORT DROPPERS. ARRGT
(to be phased out) -->	* Minimum Short Dropper	Twin Contact - 50mm Separation	Twin Contact System Short Dropper Arrangement	D/80588	-	EL 0017032	A	RAILWAYS OVERHEAD WIRING TWIN CONTACT SYSTEM SHORT DROPPER ARRANGEMENT
(to be phased out) -->			Short Dropper Arrangement	E/73613	-	EL 0034262	E	RAILWAYS OVERHEAD WIRING SHORT DROPPER ARRANGEMENT
	In-span Feeders		Catenary to Contact Feeder 91/1.12mm H.D. Copper Horizontal Loop Arrangement	C/75333	1	EL 0024221	D	RAILWAYS OVERHEAD WIRING CATENARY TO CONTACT FEEDER, 91/1.12 HD. COPPER HORIZONTAL LOOP ARRANGEMENT
		Overlap Jumpering & Additional Inspan Feeder Arr'gt - Single Contact	Overlap Jumpering & Additional In Span Feeder Arrangement	D/88173	1	EL 0004637	D	RAILWAYS OVERHEAD WIRING OVERLAP JUMPERING & ADDITIONAL IN SPAN FEEDER ARRANGEMENT.
		Overlap Jumpering & Additional Inspan Feeder Arr'gt - Twin Contact	Overlap Jumpering & Additional in Span Feeder Arrangement	D/88173	2	EL 0004638	A	RAILWAYS OVERHEAD WIRING OVERLAP JUMPERING & ADDITIONAL IN SPAN FEEDER ARRANGEMENT.
			Catenary Feeding Loop Arrangement - 270/193, 327/193 & 270/2x137 Systems with Composite Insulator	EL 0027472	-	EL 0027472	E	GENERAL RAILWAY OVERHEAD WIRING CATENARY FEEDING LOOP ARRANGEMENT
			Catenary Feeding Loop Arrangement - 165/193 System with Composite Insulator	EL 0186383	-	EL 0186383	A	GENERAL RAILWAYS OVERHEAD WIRING 165MM 2 CATENARY FEEDING LOOP ARRANGEMENT
		In-Span Feeder Spacing Chart	Single Contact - "Heavy Current" Lines	A3/89272	1	EL 0003482	B	RAILWAYS OVERHEAD WIRING CATENARY TO CONTACT FEEDER SPACING CHART FOR SINGLE CONT HEAVY CURRENT LINES
			Single Contact - "Light Current" Lines	A3/89272	2	EL 0007762	A	RAILWAYS OVERHEAD WIRING CATENARY TO CONTACT FEEDER SPACING CHART FOR SINGLE CONT HEAVY CURRENT LINES
			Single Catenary, Twin Contact Systems	A3/89272	3	EL 0007802	A	RAILWAYS OVERHEAD WIRING CATENARY TO CONTACT FEEDER SPACING CHART FOR SINGLE CATY. TWIN CONT. SYSTEMS
			Twin Catenary, Twin Contact Systems	A3/89272	4	EL 0011739	A	RAILWAYS OVERHEAD WIRING CATENARY TO CONTACT FEEDER TYPICAL SPACING CHART FOR TWIN CATY TWIN CONT SYSTEMS.
	Sliding Knuckles	Standard Arrangement	Liverpool to Glenlee - Constant Tension - Crossed Contact Sliding Knuckle	E/78019	-	EL 0018769	C	RAILWAYS OVERHEAD WIRING; LIVERPOOL TO GLENLEE; CONSTANT TENSION CROSSED CONTACTS SLIDING KNUCKLE
			Twin Contact Sliding Knuckle Arrangement	EL 0027000	-	EL 0027000	A	GENERAL; RAILWAYS OVERHEAD WIRING; TWIN CONTACT SLIDING KNUCKLE; ARRANGEMENT
	Insulated Flat Knuckle	Arrangement	Insulated Contact Wire Knuckle - Arrangement	EL 0157329	-	EL 0157329	D	CENTRAL TO REDFERN; CENTRAL FLYOVER & FLYUNDER TRACKS 0.3 TO 0.6KM APPROX; RAILWAYS OVERHEAD WIRING; INSULATED CONTACT WIRE KNUCKLE; ARRANGEMENT.

		Example	Insulated Knuckle at SW0+378 Installation Details-Proposal	EL 0159278	-	EL 0159278	B	CENTRAL TO REDFERN; CENTRAL FLYUNDER TRACKS - 0.4KM APPROX; RAILWAYS OVERHEAD WIRING; INSULATED KNUCKLE AT SW0+378; INSTALLATION DETAILS - PROPOSAL.
	Contact Half & Full Splices	Full Splice	Contact Splice (Full Splice)	A1/89648	-	EL 0002017	B	RAILWAY OVERHEAD WIRING CONTACT SPLICE
	Contact Wear Strips	Standard Contact Wire Wear Strip	Arrangement	EL 0026992	-	EL 0026992	A	GENERAL; RAILWAYS OVERHEAD WIRING; CONTACT WIRE WEAR STRIP; ARRANGEMENT
	Pennant Insulators	Catenary Pennant Insulator	Catenary Pennant Insulator Arrangement	EL 0491676	-	EL 0491676	A	GENERAL RAILWAYS OVERHEAD WIRING CATENARY PENNANT INSULATOR ARRANGEMENT
		Contact Pennant Insulator	Single Contact Pennant Insulator Arrangement	EL 0491677	-	EL 0491677	A	GENERAL RAILWAYS OVERHEAD WIRING SINGLE CONTACT PENNANT INSULATOR ARRANGEMENT
			Twin Contact Pennant Insulator Arrangement	EL 0491678	-	EL 0491678	A	GENERAL RAILWAYS OVERHEAD WIRING TWIN CONTACT PENNANT INSULATOR ARRANGEMENT
	Contact Support	Arrangement	Overline Bridges Contact Support Rigid Dropper Type 5	D/84932	-	EL 0009376	B	RAILWAYS OVERHEAD WIRING OVERLINE BRIDGES CONTACT SUPPORT RIGID DROPPER TYPE 5
2. Support & Registration						**EL BLANK**		Blank
	Mark 2 Cantilever Arrangements	1. Mainline - Twin Contact	Mark 2 Cantilever - Single Catenary Twin Contact - Standard Arrangement Types 1, 2, 1A & 2A on Mast / Portal	EL 0194773	1	EL 0194773	A	GENERAL RAILWAYS OVERHEAD WIRING MARK 2 CANTILEVER- SINGLE CATY/TWIN CONTACT STANDARD ARRANGEMENT
			Mark 2 Cantilever - Single Catenary Twin Contact - Standard Arrangement Types 1, 2 on Drop Vertical	EL 0194774	2	EL 0194774	A	GENERAL RAILWAYS OVERHEAD WIRING MARK 2 CANTILEVER- SINGLE CATY/TWIN CONTACT STANDARD ARRANGEMENT
			Mark 2 Cantilever - Single Catenary Twin Contact - Standard Arrangement Types 1A & 2A on Drop Verticals	EL 0194775	3	EL 0194775	A	GENERAL RAILWAYS OVERHEAD WIRING MARK 2 CANTILEVER- SINGLE CATY/TWIN CONTACT STANDARD ARRANGEMENT
			Mark 2 Cantilever - Single Catenary Twin Contact - Standard Arrangement Type 3 on Mast / Portal	EL 0194776	4	EL 0194776	A	GENERAL RAILWAYS OVERHEAD WIRING MARK 2 CANTILEVER- SINGLE CATY/TWIN CONTACT STANDARD ARRANGEMENT
			Mark 2 Cantilever - Single Catenary Twin Contact - Standard Arrangement Type 3A on Portal	EL 0194777	5	EL 0194777	B	GENERAL RAILWAYS OVERHEAD WIRING MARK 2 CANTILEVER- SINGLE CATY/TWIN CONTACT STANDARD ARRANGEMENT
			Mark 2 Cantilever - Single Catenary Twin Contact - Standard Arrangement Types 1S & 2S Suspension on Portal	EL 0194778	6	EL 0194778	A	GENERAL RAILWAYS OVERHEAD WIRING MARK 2 CANTILEVER- SINGLE CATY/TWIN CONTACT STANDARD ARRANGEMENT
			Mark 2 Cantilever - Single Catenary Twin Contact - Standard Arrangement Type 3S Suspension on Portal	EL 0194779	7	EL 0194779	A	GENERAL RAILWAYS OVERHEAD WIRING MARK 2 CANTILEVER- SINGLE CATY/TWIN CONTACT STANDARD ARRANGEMENT
			Mark 2 Cantilever - Single Catenary Twin Contact - Standard Arrangement Types 1G & 2G on Mast / Portal	EL 0194780	8	EL 0194780	A	GENERAL RAILWAYS OVERHEAD WIRING MARK 2 CANTILEVER- SINGLE CATY/TWIN CONTACT STANDARD ARRANGEMENT
			Mark 2 Cantilever - Single Catenary Twin Contact - Standard Arrangement Type 3G on Mast / Portal	EL 0194781	9	EL 0194781	A	GENERAL RAILWAYS OVERHEAD WIRING MARK 2 CANTILEVER- SINGLE CATY/TWIN CONTACT STANDARD ARRANGEMENT
			Mark 2 Cantilever - Single Catenary Twin Contact - Standard Arrangement Types 1GS & 2GS Suspension on Portal	EL 0194782	10	EL 0194782	A	GENERAL RAILWAYS OVERHEAD WIRING MARK 2 CANTILEVER- SINGLE CATY/TWIN CONTACT STANDARD ARRANGEMENT
			Mark 2 Cantilever - Single Catenary Twin Contact - Standard Arrangement Type 3GS Suspension on Portal	EL 0194783	11	EL 0194783	A	GENERAL RAILWAYS OVERHEAD WIRING MARK 2 CANTILEVER- SINGLE CATY/TWIN CONTACT STANDARD ARRANGEMENT
		2. Alternative (Heavy Current) - Twin Catenary / Twin Contact	Mark 2 Cantilever - Twin Catenary Twin Contact - Standard Arrangement Types 1, 2, 1A & 2A on Mast / Portal	A1/89233	1	EL 0003384	C	RAILWAYS OVERHEAD WIRING MARK 2 CANTILEVER TWIN CATENARY TWIN CONTACT STANDARD ARRANGEMENT

			Mark 2 Cantilever - Twin Catenary Twin Contact - Standard Arrangement Types 1 & 2 on Drop Vertical	A1/89233	2	EL 0003385	C	RAILWAYS OVERHEAD WIRING MARK 2 CANTILEVER TWIN CATENARY TWIN CONTACT STANDARD ARRANGEMENT
			Mark 2 Cantilever - Twin Catenary Twin Contact - Standard Arrangement Types 1A & 2A on Drop Vertical	A1/89233	3	EL 0003386	C	RAILWAYS OVERHEAD WIRING MARK 2 CANTILEVER TWIN CATENARY / TWIN CONTACT STANDARD ARRANGEMENT
			Mark 2 Cantilever - Twin Catenary Twin Contact - Standard Arrangement Type 3 on Mast / Portal	A1/89233	4	EL 0003387	C	RAILWAYS OVERHEAD WIRING MARK 2 CANTILEVER TWIN CATENARY / TWIN CONTACT STANDARD ARRANGEMENT
			Mark 2 Cantilever - Twin Catenary Twin Contact - Standard Arrangement Type 3A on Portal	A1/89233	5	EL 0003388	C	RAILWAYS OVERHEAD WIRING MARK 2 CANTILEVER TWIN CATENARY / TWIN CONTACT STANDARD ARRANGEMENT
			Mark 2 Cantilever - Twin Catenary Twin Contact - Standard Arrangement Types 1S & 2S Suspension on Portal	A1/89233	6	EL 0003389	C	RAILWAYS OVERHEAD WIRING MARK 2 CANTILEVER TWIN CATENARY / TWIN CONTACT STANDARD ARRANGEMENT
			Mark 2 Cantilever - Twin Catenary Twin Contact - Standard Arrangement Type 3S Suspension on Portal	A1/89233	7	EL 0003390	C	RAILWAYS OVERHEAD WIRING MARK 2 CANTILEVER TWIN CATENARY / TWIN CONTACT STANDARD ARRANGEMENT
			Mark 2 Cantilever - Twin Catenary Twin Contact - Standard Arrangement Types 1G & 2G on Mast / Portal	A1/89233	8	EL 0003391	C	RAILWAYS OVERHEAD WIRING MARK 2 CANTILEVER TWIN CATENARY / TWIN CONTACT STANDARD ARRANGEMENT
			Mark 2 Cantilever - Twin Catenary Twin Contact - Standard Arrangement Type 3G on Portal	A1/89233	9	EL 0003392	C	RAILWAYS OVERHEAD WIRING MARK 2 CANTILEVER TWIN CATENARY / TWIN CONTACT STANDARD ARRANGEMENT
			Mark 2 Cantilever - Twin Catenary Twin Contact - Standard Arrangement Types 1GS & 2GS Suspension on Portal	A1/89233	10	EL 0003393	C	RAILWAYS OVERHEAD WIRING MARK 2 CANTILEVER TWIN CATENARY / TWIN CONTACT STANDARD ARRANGEMENT
			Mark 2 Cantilever - Twin Catenary Twin Contact - Standard Arrangement Type 3GS Suspension on Portal	A1/89233	11	EL 0003394	C	RAILWAYS OVERHEAD WIRING MARK 2 CANTILEVER TWIN CATENARY / TWIN CONTACT STANDARD ARRANGEMENT
		3. Siding / Cross-over - Single Contact	Mark 2 Cantilever - Single Contact - Standard Arrangement Types 1, 2, 1A & 2A on Mast / Portal	A1/86719	1	EL 0006173	B	RAILWAYS OVERHEAD WIRING MARK 2 CANTILEVER SINGLE CONTACT TYPICAL CROSS SECTION
			Mark 2 Cantilever - Single Contact - Standard Arrangement Types 1 & 2 on Drop Vertical	A1/86719	2	EL 0006174	B	RAILWAYS OVERHEAD WIRING MARK 2 CANTILEVER SINGLE CONTACT TYPICAL CROSS SECTION
			Mark 2 Cantilever - Single Contact - Standard Arrangement Types 1A & 2A on Drop Vertical	A1/86719	3	EL 0006175	B	RAILWAYS OVERHEAD WIRING MARK 2 CANTILEVER SINGLE CONTACT TYPICAL CROSS SECTION
			Mark 2 Cantilever - Single Contact - Standard Arrangement Type 3 on Mast / Portal	A1/86719	4	EL 0006176	B	RAILWAYS OVERHEAD WIRING MARK 2 CANTILEVER SINGLE CONTACT TYPICAL CROSS SECTION
			Mark 2 Cantilever - Single Contact - Standard Arrangement Types 1S & 2S Suspension on Portal	A1/86719	5	EL 0006177	B	RAILWAYS OVERHEAD WIRING MARK 2 CANTILEVER SINGLE CONTACT TYPICAL CROSS SECTION
			Mark 2 Cantilever - Single Contact - Standard Arrangement Type 3S Suspension on Portal	A1/86719	6	EL 0006178	B	RAILWAYS OVERHEAD WIRING MARK 2 CANTILEVER SINGLE CONTACT TYPICAL CROSS SECTION
			Mark 2 Cantilever - Single Contact - Standard Arrangement Type 3A on Portal	A1/86719	7	EL 0006179	B	RAILWAYS OVERHEAD WIRING MARK 2 CANTILEVER SINGLE CONTACT TYPICAL CROSS SECTION

			Mark 2 Cantilever - Single Contact - Standard Arrangement Types 1GS & 2GS Suspension on Portal	A1/86719	8	EL 0006180	B	RAILWAYS OVERHEAD WIRING MARK 2 CANTILEVER SINGLE CONTACT TYPICAL CROSS SECTION
			Mark 2 Cantilever - Single Contact - Standard Arrangement Types 1G & 2G on Mast / Portal	A1/86719	9	EL 0006181	B	RAILWAYS OVERHEAD WIRING MARK 2 CANTILEVER SINGLE CONTACT TYPICAL CROSS SECTION
			Mark 2 Cantilever - Single Contact - Standard Arrangement Type 3G on Mast / Portal	A1/86719	10	EL 0006182	B	RAILWAYS OVERHEAD WIRING MARK 2 CANTILEVER SINGLE CONTACT TYPICAL CROSS SECTION
			Mark 2 Cantilever - Single Contact - Standard Arrangement Type 3GS Suspension on Portal	A1/86719	11	EL 0006183	B	RAILWAYS OVERHEAD WIRING MARK 2 CANTILEVER SINGLE CONTACT TYPICAL CROSS SECTION
	Pull-off Arrangements	Typical Standard Arrangement - Single Contact	Types 1 & 2, Single Contact Pull-Off Standard Arrangement	-	-	EL 0475858	A	GENERAL RAILWAYS OVERHEAD WIRING TYPE 1 & 2 SINGLE CONTACT PULL-OFF STANDARD ARRANGEMENT
			Type 3, Single Contact Pull-Off Standard Arrangement	-	-	EL 0475859	A	GENERAL RAILWAYS OVERHEAD WIRING TYPE 3 SINGLE CONTACT PULL-OFF STANDARD ARRANGEMENT
		Typical Standard Arrangement - Twin Contact Contact	Types 1 & 2, Twin Contact Pull-Off Standard Arrangement	-	-	EL 0475865	A	GENERAL RAILWAYS OVERHEAD WIRING TYPE 1 & 2 TWIN CONTACT PULL-OFF STANDARD ARRNGEMENT
			Type 3, Twin Contact Pull-Off Standard Arrangement	-	-	EL 0475866	A	GENERAL RAILWAYS OVERHEAD WIRING TYPE 3 TWIN CONTACT PULL-OFF STANDARD ARRNGEMENT
		Pull-Off For Fixed Mid-Point Arrangement	Pull-Off For Fixed Mid-Point Arrangement (Fitting 185/3)	EL 0518103	-	EL 0518103	A	GENERAL RAILWAYS OVERHEAD WIRING PULL-OFF FOR TUNNEL FIXED MID-POINT (FMP) ARRANGEMENT
	Bridge Arrangements	Examples	Heathcote - Wilsons Pde OLB - Arrangement of Fittings	EL 0034474	-	EL 0034474	A	HEATHCOTE ILLAWARRA LINE 32.079KM RAILWAYS OVERHEAD WIRING WILLSON PARADE OVERLINE BRIDGE ARRANGEMENT OF FITTINGS
			Turramurra - Cherry St OLB - Arrangement of Fittings	EL 0190277	-	EL 0190277	B	TURRAMURRA; NORTH SHORE LINE - 21.115KMS APPROX; RAILWAYS OVERHEAD WIRING; OVERLINE BRIDGE AT CHERRY STREET; ARRANGEMENT OF FITTINGS - AS BUILT
			Turramurra - Warragal Rd OLB - Arrangement of Fittings	EL 0190275	-	EL 0190275	B	TURRAMURRA; NORTH SHORE LINE - 20.13KMS APPROX; RAILWAYS OVERHEAD WIRING; OVERLINE BRIDGE AT WARRIGAL ROAD; ARRANGEMENT OF FITTINGS; AS BUILT
			Flyunder Support & Registration - Standard Arrangement Types 1 & 2	EL 0157852	1	EL 0157852	A	CENTRAL TO REDFERN; CENTRAL FLYUNDER TRACKS - 0.3 TO 0.6KM APPROX; FLYUNDER SUPPORT & REGISTRATION; STANDARD ARRANGEMENT TYPES 1 & 2 - PROPOSAL.
			Flyunder Support & Registration - Standard Arrangement Type 3	EL 0159805	2	EL 0159805	A	CENTRAL TO REDFERN; CENTRAL FLYUNDER TRACKS - 0.3 TO 0.6KM APPROX; RAILWAYS OVERHEAD WIRING; FLYUNDER SUPPORT & REGISTRATION; STANDARD ARRANGEMENT - PROPOSAL.
	Tunnel Arrangements	Tunnel Cantilever	Tunnel Cantilever - Mark 2	EL 0189498	-	EL 0189498	D	GENERAL RAILWAYS OVERHEAD WIRING TUNNEL CANTILEVER- MARK 2 ARRANGEMENT
		Tunnel Cantilever	Tunnel Cantilever - Mark 3 (For Single Track Tunnels)	EL 0357173	-	EL 0357173	A	GENERAL RAILWAYS OVERHEAD WIRING MARK 3 TUNNEL CANTILEVER ARRANGEMENT
	Auxiliary Feeder	Typical "Gallows" Standard Arrangement	Support for Auxiliary Feeder	D/86583	1	EL 0006026	E	RAILWAYS OVERHEAD WIRING SUPPORTS FOR AUXILIARY FEEDER
		Typical "Gallows" Standard Arrangement on Back to Back Cantilever	Support for Auxiliary Feeder	D/86583	2	EL 0006027	B	RAILWAYS OVERHEAD WIRING; SUPPORTS FOR AUXILIARY FEEDER
3. Support Structures						**EL BLANK**		Blank
4. Anchors	Tension Regulator Arrangements	Single Catenary	Twin Tension Regulator Assembly (270mm² Caty / 2x137mm² Contact, T/w =588m)	EL 0237849	-	EL 0237849	A	GENERAL RAILWAYS OVERHEAD WIRING TENSION REGULATOR - SINGLE CATY / TWIN CONT STANDARD ARRANGEMENT - OHW SYSTEM 2
			Mark 2 Tension Regulator Assembly (510/193, 327/193 & 270/193, T/w =550m OHW Systems)	EL 0237851	-	EL 0237851	A	GENERAL RAILWAYS OVERHEAD WIRING TENSION REGULATOR - SINGLE CATY/SINGLE CONT STANDARD ARRANGEMENT - OHW SYSTEMS 8, 9 & 10
			Mark 2 Tension Regulator Assembly (165/193, T/w =550m OHW System)	EL 0023685	-	EL 0023685	C	GENERAL RAILWAYS OVERHEAD WIRING REGULATOR FOR 165MM² CATY/193MM² CONTACT STANDARD ARRANGEMENT
			Twin Mast Regulator Assembly (270mm² Caty / 2x137mm² Cont, T/w =588m & 270mm² Caty / 193mm² Cont, T/w =550m, OHW Systems)	EL 0215130	-	EL 0215130	B	RAILWAYS OVERHEAD WIRING MARK 2 CANTILEVER TWIN MAST REGULATOR ASSEMBLY STANDARD ARRANGEMENT

			Eastern Suburbs Railway Tension Regulator [Gas Tensioner Replacement] (270mm² Caty @ 19.43kN / 2x137mm² Contact @ 2x9.72kN; T/w =381m)	EL 0474468	-	EL 0474468	A	EASTERN SUBURBS RAILWAY DOWN & UP EASTERN SUBURBS LINE RAILWAYS OVERHEAD WIRING REGULATOR - ESR 270MM²CATY / 2X137MM² CONT ARRANGEMENT
			Mark 2 Tension Regulator Assembly (327/193, T/w =344m System 1; 270/193, T/w =371m System 4 OHW Systems)	EL 0287234	-	EL 0287234	A	GENERAL RAILWAYS OVERHEAD WIRING TENSION REGULATOR COMBINED CATY / CONT STANDARD ARRANGEMENT OHW SYSTEMS 1 & 4
		Twin Catenary	Tension Regulator Assembly (2x270mm² Caty / 2x137mm² Cont & 2x165mm² Caty / 2x137mm² Cont, T/w =550m OHW Systems)	EL 0215038	-	EL 0215038	C	GENERAL RAILWAYS OVERHEAD WIRING MOVING ANCHOR - TWIN CATENARY/TWIN CONTACT STANDARD ARRANGEMENT
	Fixed Anchor Arrangements	Single Catenary	Fixed Anchor Arrangement (270mm² Caty / 2x137mm² Cont, T/w =588m OHW System)	EL 0237850	-	EL 0237850	A	GENERAL RAILWAYS OVERHEAD WIRING FIXED ANCHOR - SINGLE CATENARY/TWIN CONTACT STANDARD ARRANGEMENT OHW SYSTEM 2
			Free Standing Anchor Mast Fixed Anchor Arrangement (270mm² Caty / 2x137mm² Cont, T/w =588m & 165/193, 270/193, 327/193, T/w =550m, OHW Systems)	EL 0166885	-	EL 0166885	B	GENERAL RAILWAYS OVERHEAD WIRING FIXED ANCHOR ON FREE STANDING MAST ARRANGEMENT
			Mark 2 Fixed Anchor Arrangement (165/193, 270/193, 327/193 & 510/193 T/w =550m OHW Systems)	EL 0237852	-	EL 0237852	A	GENERAL RAILWAYS OVERHEAD WIRING FIXED ANCHOR - SINGLE CATY/SINGLE CONTACT STANDARD ARRANGEMENT OHW SYSTEM 8, 9 & 10
		Twin Catenary	Fixed Anchor Arrangement (2x165mm² Caty / 2x137mm² Cont & 2x270mm² Caty / 2x137mm² Cont, T/w =550m, OHW System)	EL 0215037	-	EL 0215037	B	GENERAL RAILWAYS OVERHEAD WIRING FIXED ANCHOR FOR TWIN CATENARY/TWIN CONTACT STANDARD ARRANGEMENT OHW SYSTEM 12 & 15
		Examples	Goulburn St Parking Station - Catenary & Twin Contact Anchor on Ceiling - Standard Arrangement	EL 0157306	-	EL 0157306	B	GOULBURN ST PARKING STATION; CITY RAILWAY TRACKS 0.4KM TO 0.6KM APPROX; RAILWAYS OVERHEAD WIRING; CATENARY & TWIN CONTACT ANCHOR; STANDARD ARRANGEMENT - PROPOSAL.
	Mid-point Arrangements	1. Mainline - Twin Contact	Waterfall to Port Kembla Cantilever Construction - Mid Point Anchor Arrangement	A/85033	1	EL 0009255	A	RAILWAYS OVERHEAD WIRING WATERFALL TO PORT KEMBLA CANTILEVER CONSTRUCTION MID POINT ANCHOR ARRANGEMENT.
			Waterfall to Port Kembla Cantilever Construction - Mid Point Anchor Arrangement	A/85033	2	EL 0009256	A	RAILWAYS OVERHEAD WIRING WATERFALL TO PORT KEMBLA CANTILEVER CONSTRUCTION MID POINT ANCHOR ARRANGEMENT.
		3. Siding / Cross-over - Single Contact	Mark 2 Cantilever T/W=550m Mid Point Anchor Arrangement	A/86799	1	EL 0006282	A	RAILWAYS OVERHEAD WIRING MARK 2. CANTILEVER T/W = 550M MID POINT ANCHOR ARRANGEMENT
			Mark 2 Cantilever T/W=550m Mid Point Anchor Arrangement	A/86799	2	EL 0006283	A	RAILWAYS OVERHEAD WIRING MARK 2. CANTILEVER T/W = 550M MID POINT ANCHOR ARRANGEMENT
			Mark 2 Cantilever T/W=550m Mid Point Anchor Arrangement	A/86799	3	EL 0006284	A	RAILWAYS OVERHEAD WIRING MARK 2. CANTILEVER T/W = 550M MID POINT ANCHOR ARRANGEMENT
		4. Multi-track Portal Arrangement	Mark 2 Cantilever Multi Track Regulated System Fixed Mid Point Arrangement Type 1 (Single & Twin Catenary)	A1/89297	1	EL 0003512	D	RAILWAYS OVERHEAD WIRING MARK 2 CANTILEVER MULTI TRACK REGULATED SYSTEM FIXED- MID POINT ARRANGEMENT
			Mark 2 Cantilever Multi Track Regulated System Fixed Mid Point Arrangement Type 2 & 3 (Single & Twin Catenary)	A1/89297	2	EL 0012047	C	RAILWAYS OVERHEAD WIRING MARK 2 CANTILEVER MULTI TRACK REGULATED SYSTEM FIXED MID- POINT ARRANGEMENT
	Anchor Guy	Guy Anchor for Anchor Masts	Guy Anchor for Anchor Masts - Standard Arrangement	EL 0237853	-	EL 0237853	A	GENERAL RAILWAYS OVERHEAD WIRING GUY ANCHOR FOR ANCHOR MASTS STANDARD ARRANGEMENT
5. Airgaps / Overlaps		Short Bay Overlap	Twin Contact Short Bay Overlap	A1/90191	-	EL 0001110	A	GENERAL RAILWAYS OVERHEAD WIRING TWIN CONTACT SHORT BAY OVERLAP ARRANGEMENT
6. Section Insulators	Type 6 S.I.	Standard Arrangement	Type 6 Section Insulator - Body - Arrangement	EL 0166884	-	EL 0166884	A	GENERAL; RAILWAYS OVERHEAD WIRING TYPE 6 SECTION INSULATOR - BODY ARRANGEMENT
			Type 6 Section Insulator - Support - Arrangement for Single Catenary	EL 0030508	-	EL 0030508	B	GENERAL RAILWAYS OVERHEAD WIRING TYPE 6 SECTION INSULATOR — SUPPORT ARRANGEMENT — FOR SINGLE CATENARY

			Type 6 SI - BICC Arrangement Sh. 1 of 2	EL 0052290		EL 0052290	B	GENERAL RAILWAYS OVERHEAD WIRING TYPE 6 S.I.(SWITCHED) IN COMPOUND OHW ARRANGEMENT
			Type 6 SI - BICC Arrangement Sh. 2 of 2	EL 0052291		EL 0052291	A	GENERAL; RAILWAYS OVERHEAD WIRING; TYPE 6 S.I.(SWITCHED) IN COMPOUND OHW; ARRANGEMENT
7. Switches	Switch Arrangements	Standard Arrangements	Equipotential Mat for Switch - Arrangement	EL 0150615	-	EL 0150615	C	RAILWAYS OVERHEAD WIRING EQUIPOTENTIAL MAT FOR SWITCH ARRANGEMENT
			1500V Switch Operator Platform - Arrangement	EL 0491331	-	EL 0491331	B	GENERAL RAILWAYS OVERHEAD WIRING 1500V SWITCH OPERATOR PLATFORM ARRANGEMENT
			1500V Isolating / Rail-Connecting Switch - Mast Mount - Left-Hand - Arrangement	EL 0057425	-	EL 0057425	C	GENERAL RAILWAYS OVERHEAD WIRING 1500V ISOL / RAIL CONNECTING SW - MAST MOUNT ARRANGEMENT - LEFT HAND VERSION
			1500V Isolating / Rail-Connecting Switch - Mast Mount - Right-Hand - Arrangement	EL 0077250	-	EL 0077250	C	GENERAL RAILWAYS OVERHEAD WIRING 1500V ISOL / RAIL CONNECTING SW - MAST MOUNT ARRANGEMENT - RIGHT HAND VERSION
			1500V Isolating Switch - 2 Pole - Mast Mount - Left-Hand - Arrangement	EL 0077251	-	EL 0077251	C	GENERAL RAILWAYS OVERHEAD WIRING 1500V ISOLATING SWITCH - 2 POLE - MAST MOUNT ARRANGEMENT - LEFT HAND VERSION
			1500V Isolating Switch - 2 Pole - Mast Mount - Right-Hand - Arrangement	EL 0077252	-	EL 0077252	C	GENERAL RAILWAYS OVERHEAD WIRING 1500V ISOLATING SWITCH - 2 POLE - MAST MOUNT ARRANGEMENT - RIGHT HAND VERSION
			1500V 2 Position Switch - Mast Mount - Left-Hand - Arrangement	EL 0282734	-	EL 0282734	C	GENERAL RAILWAYS OVERHEAD WIRING 1500V - 2 POSITION SWITCH - MAST MOUNT ARRANGEMENT - LEFT HAND VERSION
			1500V 2 Position Switch - Mast Mount - Right-Hand - Arrangement	EL 0282735	-	EL 0282735	C	GENERAL RAILWAYS OVERHEAD WIRING 1500V - 2 POSITION SWITCH - MAST MOUNT ARRANGEMENT - RIGHT HAND VERSION
			1500V Rail-Connecting Switch - Mast Mount - Left-Hand - Arrangement	EL 0282806	-	EL 0282806	B	GENERAL RAILWAYS OVERHEAD WIRING 1500V - RAIL CONNECTING SWITCH - MAST MOUNT ARRANGEMENT- LEFT HAND VERSION
			1500V Rail-Connecting Switch - Mast Mount - Right-Hand - Arrangement	EL 0282807	-	EL 0282807	B	GENERAL RAILWAYS OVERHEAD WIRING 1500V - RAIL CONNECTING SWITCH - MAST MOUNT ARRANGEMENT- RIGHT HAND VERSION
		Recent Examples	Switched Overlap on PP Masts	EL 0455574		EL 0455574	B	GENERAL RAILWAYS OVERHEAD WIRING SWITCHED OVERLAP ON PP MASTS SWITCHING ARRANGEMENT
			Switched Overlap at Location SW1+002 - Switch Arrangement	EL 0157308	-	EL 0157308	B	CENTRAL TO REDFERN ILLAWARRA TRACKS 1.KM APPROX RAILWAY OVERHEAD WIRING SWITCHED OVERLAP AT LOCATION SW1+002 SWITCHING ARRANGEMENTS
			Switched Overlap at Location B5+942 - Switch Arrangement	EL 0026361	-	EL 0026361	B	SYDENHAM TO MARRICKVILLE UP & DN BANKSTOWN LINE 5.96KM APPROX RAILWAYS OVERHEAD WIRING SWITCHED OVERLAP AT LOCATION B5+942 SWITCHING ARRANGEMENT - AS BUILT
			1500V Switch on Platform - Arrangement (at Central) - Sh. 1 of 2	EL 0025706	-	EL 0025706	C	CENTRAL TO REDFERN; ILLAWARRA TRACKS - 0.28KM APPROX.; RAILWAYS OVERHEAD WIRING; SWITCH LOCATION SW0+279; SWITCHING ARRANGEMENT
			1500V Switch on Platform - Arrangement (at Central) - Sh. 2 of 2	EL 0025707	-	EL 0025707	C	CENTRAL TO REDFERN; ILLAWARRA TRACKS - 0.25KM APPROX.; RAILWAYS OVERHEAD WIRING; SWITCH LOCATION SW0+279; SWITCHING ARRANGEMENT
			Switching Arrang't - Strathfield Location MS11+976 - Sh. 1 of 2	EL 0237888	-	EL 0237888	A	STRATHFIELD MAIN WEST LINE - 11.976KM(APPROX) RAILWAYS OVERHEAD WIRING LOCATION MS11+976 SWITCHING ARRANGEMENT
			Switching Arrang't - Strathfield Location MS11+976 - Sh. 2 of 2	EL 0237889	-	EL 0237889	A	STRATHFIELD MAIN WEST LINE - 11.976KM(APPROX) RAILWAYS OVERHEAD WIRING LOCATION MS11+976 SWITCHING ARRANGEMENT
			Switching Arrang't - Strathfield Location MS11+647	EL 0232991	-	EL 0232991	B	STRATHFIELD JUNCTION MAIN WEST LINE - 11.6KM APPROX RAILWAYS OVERHEAD WIRING LOCATION MS 11+647 SWITCHING ARRANGEMENT - FOR CONSTRUCTION
			Switching Arrang't - Strathfield Location MS12+494	EL 0232990	-	EL 0232990	A	STRATHFIELD JUNCTION MAIN WEST LINE - 12.5KM APPROX RAILWAYS OVERHEAD WIRING LOCATION MS12+494 - DOWN LOCAL SWITCHING ARRANGEMENT - FOR CONSTRUCTION
			Switched Overlap at Central, Location SW0+707, Up Suburban	EL 0400975	-	EL 0400975	A	CENTRAL - REDFERN ILLAWARRA LINE 0.7KM APPROX RAILWAYS OVERHEAD WIRING SWITCHED OVERLAP FOR UP SUBURBAN AT SW0+707 SWITCHING ARRANGEMENT
			North Sydney - 7 Switch Bank @ Location NS4+986 - Sh. 1 of 4	EL 0282942	-	EL 0282942	B	NORTH SYDNEY NORTH SHORE LINE 5.00KM APPPOX. RAILWAYS OVERHEAD WIRING 7 SWITCH BANK AT LOCATION NS4+986 SWITCH ARRANGEMENT
			North Sydney - 7 Switch Bank @ Location NS4+986 - Sh. 2 of 4	EL 0282943	-	EL 0282943	A	NORTH SYDNEY NORTH SHORE LINE 5.00KM APPPOX. RAILWAYS OVERHEAD WIRING 7 SWITCH BANK AT LOCATION NS4+986 SWITCH ARRANGEMENT
			North Sydney - 7 Switch Bank @ Location NS4+986 - Sh. 3 of 4	EL 0282944	-	EL 0282944	A	NORTH SYDNEY NORTH SHORE LINE 5.00KM APPPOX. RAILWAYS OVERHEAD WIRING 7 SWITCH BANK AT LOCATION NS4+986 SWITCH ARRANGEMENT
			North Sydney - 7 Switch Bank @ Location NS4+986 - Sh. 4 of 4	EL 0282945	-	EL 0282945	B	NORTH SYDNEY NORTH SHORE LINE 5.00KM APPPOX. RAILWAYS OVERHEAD WIRING 7 SWITCH BANK AT LOCATION NS4+986 SWITCH ARRANGEMENT
8. Feeding	Cable / Aerial Feeding Arrangement	Standard Arrangement	Cable Feeding Arrangement	B/83384	2	EL 0011878	H	RAILWAYS OVERHEAD WIRING CABLE FEEDING ARRANGEMENT

	Airgap Feeding Arrangement	Typical Arrangement - 1	Typical Airgap Feeding Arrangement Wiring System 270 mm^2 Catenary 2x137 mm^2 Contact	B/85954	1	EL 0008074	B	RAILWAYS OVERHEAD WIRING TYPICAL AIRGAP FEEDING ARRANGEMENT WIRING SYSTEM 270MM2 CATENARY 2X137MM2 CONTACT
		Typical Arrangement - 2	Typical Airgap Feeding Arrangement Wiring System 270 mm^2 Catenary 2x137 mm^2 Contact	B/85954	2	EL 0008075	C	RAILWAYS OVERHEAD WIRING TYPICAL AIRGAP FEEDING ARRANGEMENT WIRING SYSTEM 270MM2 CATENARY 2X137MM2 CONTACT
		Typical Arrangement - 3	Typical Airgap Feeding Arrangement Wiring System 270 mm^2 Catenary 2x137 mm^2 Contact	B/85954	3	EL 0008076	B	RAILWAYS OVERHEAD WIRING TYPICAL AIRGAP FEEDING ARRANGEMENT WIRING SYSTEM 270MM2 CATENARY 2X137MM2 CONTACT
		Recent Examples	Feeding Arrangement - Turramurra Location MH21+289	EL 0011619	-	EL 0011619	B	TURRAMURRA NORTH SHORE LINE- 21.289KM RAILWAYS OVERHEAD WIRING FEEDING LOCATION AT MH21+289 FEEDING ARRANGEMENT
			Feeding Arrangement - Yennora Location G27+986	EL 0065499	-	EL 0065499	C	YENNORA OLD SOUTH LINE 27+986KM RAILWAYS OVERHEAD WIRING YENNORA SUBSTATION AT G27+986 FEEDIMG ARRANGEMENT AND TRACKSIDE NEGATIVE BUS
9. Surge Protection						**EL BLANK**		Blank
10. Over-run Protection	Skid Arrangement	Recent Examples	Eveleigh - Skid - Termination Arrangement	EL 0166574	-	EL 0166574	C	EVELEIGH; MILLENIUM TRAIN SERVICING FACILITY; RAILWAYS OVERHEAD WIRING; SKID - TERMINATION ARRANGEMENT
11. Signs	Structure Location Number	Standard Arrangement	Mast Label Details and Location	D/86098	-	EL 0006766	D	RAILWAYS OVERHEAD WIRING MAST LABEL DETAILS & LOCATION.
12. Bonding & Earthing	OHW Structures	Copper Bonding Arrangement	Bonding on Mast to Rail Arrangement	D/83382	3	EL 0011875	F	RAILWAYS OVERHEAD WIRING BONDING OF MAST TO RAIL ARRANGEMENT.
		Steel Bonding Arrangement	Bonding on Mast to Rail Arrangement	D/83382	4	EL 0011876	D	RAILWAYS OVERHEAD WIRING BONDING OF MAST TO RAIL ARRANGEMENT
		Isolated Masts (eg. on Viaduct)	Aerial Bonding Arrangement for Isolated Masts	C/89064	-	EL 0002963	B	RAILWAY OVERHEAD WIRING BONDING ARRANGEMENT FOR ISOLATED MASTS
		Earthing	Earthing of OHW Structures - Standard Arrangement	EL 0001334	-	EL 0001334	A	GENERAL RAILWAYS OVERHEAD WIRING EARTHING OF OVERHEAD WIRING STRUCTURE STANDARD ARRANGEMENT
	Bridges	Bonding of Bridge Attachments - Typical Standard Arrangement	Jack Arch Bridges Typical Bonding Arrangement	B/85797	-	EL 0007855	B	RAILWAYS OVERHEAD WIRING JACK ARCH BRIDGES TYPICAL BONDING ARRANGEMENT
	Secondary Insulation	Secondary Insulation on Typical Cantilever	Secondary Insulation on Typical Cantilever	EL 0282964	-	EL 0282964	C	GENERAL RAILWAYS OVERHEAD WIRING SECONDARY INSULATION ON TYPICAL CANTILEVER ARRANGEMENT
	Tertiary Insulation	Tertiary Insulation Scheme Under Air Space Development	North Sydney - Tertiary Insulationfor Air Space - Bonding Arrangement - Sheet 1 of 2	EL 0523806	-	EL 0523806	A	NORTH SYDNEY NORTH SHORE LINE - 5KM APPROX RAILWAYS OVERHEAD WIRING TERTIARY INSULATION FOR AIR SPACE BONDING ARRANGEMENT
	Tertiary Insulation	Tertiary Insulation Scheme Under Air Space Development	North Sydney - Tertiary Insulationfor Air Space - Bonding Arrangement - Sheet 2 of 2	EL 0523817	-	EL 0523817	B	NORTH SYDNEY NORTH SHORE LINE - 5KM APPROX. RAILWAYS OVERHEAD WIRING TERTIARY INSULATION FOR AIR SPACE BONDING ARRANGEMENT

8.3 SOFTWARE TOOLS

The following table lists the various OHW design software tools developed for Sydney's OHW, available for use when designing new OHW or making changes to existing OHW.

Note that this list is a snapshot in time (2014) and therefore is probably not up to date. Before using the information, please check for an updated list (possibly on the internet).

RailCorp, NSW - OHW Computer Program Register - Current Versions

Updated : 14/08/2012

Program Name	Current Version	Platform	Description	Comments
1. General				
MinCont.xlt	**Mark 3.0**	Excel	Calculates the Minimum Contact Height in a Bay of Fixed-Anchored OHW	Fixed-Anchored OHW only.
Overlap.xlt	**3.4**	Excel	Overlap Design Program (Excel 2003).	"OverlapDescription20.pdf" file is available which helps explain Overlap
PanGauge.xlt	**Mark 4.0**	Excel	Pantograph Gauge - Dual Tracks	For pantograph clearance checks only.
WeightSet_2-2.xlt	**Mark 2.2**	Excel	Weight Tension Regulator Set-up Program	To be initiated by Design, then handed over to Construction, then to District.
KF-row4-7.xlt	**4.7**	Excel	OHW Design - suite of design tools	Added 19/5/2011
2. Droppers				
AirDrop.exe	**File Date 4/08/1993**	MS-DOS	Dropper Program for Airgaps - Single Overlap Bay only (Regulated OHW).	
FixDrop.exe	**File Date 12/02/1997**	MS-DOS	Dropper Program - Fixed Anchored OHW.	
RegDrop.exe	**File Date 20/06/2006**	MS-DOS	Dropper Program - Regulated OHW.	
3. Cantilevers				
CCALC.exe	**4.3**	MS-Dos	Mark 2 Cantilever Program (Referencing Standard Arrangements) - Generates construction	
Ccalc-Input.xlt	**Mark 2.5**	Excel	Input Sheet for CCALC.	
Mast.exe	**2.0**	MS-Dos	Mark 1 Cantilever Program (Referencing Standard Arrangements) - Generates construction	eg. Gosford to Newcastle
MastWood.exe	**2.0**	MS-Dos	Mark 1 Cantilever Program for Installation on Wood Poles (Referencing Standard Arrangements) -	
PO_Calc.xlt	**Mark 2.9**	Excel	Pull-Off Calc Program (Referencing Standard Arrangements) - Generates construction	
PO-Arm2d.xls	**Mark 1.1**	Excel	List of Standard Pull-Off Arms (Single & Twin Contact).	
TCalc.xlt	**Mark 1.0**	Excel	Generates Tunnel Cantilever construction details.	
4. Structures				
DV_Position.xlt	**Mark 2.2**	Excel	Drop Vertical Length & Position Table.	For Civil Design to size & locate Drop Verticals on portal structures.
Load-Dgm.xlt	**Mark 3.0**	Excel	OHW Structure Loading Diagrams.	For communicating loading information to Civil Design for OHW

Notes :

1. This list provides the latest status of the various RailCorp OHW Design computer programs.
2. It is intended that this list will be updated & re-published on the RailCorp IntraNet whenever program revisions change.
3. Before using any of these programs, please check the latest issue of this list to ensure that the program is current.
4. These programs are to be used only on RailCorp projects.
5. An updated copy of each program can be obtained via the relevant RailCorp Design Delivery Manager.
6. Because of email restrictions, " *.exe" files cannot be posted out by email.

Table 54 - List of OHW Design Software

8.4 RELEVANT UNIT CONVERSIONS

The following table lists a number of unit conversions applicable to OHW work.

Note that there are no electrical unit conversions below, because they are mostly universally standard.

Aspect	Metric → Imperial		Imperial → Metric		Comments
Length	1 mm	0.03937 in	1 in	25.4 mm	in = inch = ”
	1 mm	0.00328 ft	1 ft	304.8 mm	ft = foot = ’
	1 m	3.281 ft	1 ft	0.3048 m	
	1 km	0.62137 mi	1 mi	1.6093 km	mi = mile
Area	1 mm²	0.00155 in²	1 in²	645.16 mm²	in² = sq. in.
Speed	1 m/s	3.28 ft/s	1 ft/s	0.3048 m/s	ft/s = feet per second
	1 km/h	0.6214 mi/h	1 mi/h	1.609 km/h	mi/h = miles per hour
Mass	1 kg	2.2046 lb	1 lb	0.4536 kg	lb = pound
	1 tonne	1.1023 ton (US) 0.9842 ton (UK)	1 ton (US) 1 ton (UK)	0.9072 tonne 1.016 tonne	Ton (US) = short ton Ton (UK) = long ton
Force	1 N	0.2248 lb	1 lbf	4.448 N	lbf = pound force
	1 kN	224.8 lbf	1 lbf	0.004448 kN	
Torque	1 Nm	0.7376 lb.ft	1 lb.ft	1.356 Nm	lb.ft = pounds feet
Temperature	°C = (°F – 32) × 5 / 9		°F = (°C × 1.8) + 32		
	0 °C = 32 °F				Freezing Point
	100 °C = 212 °F				Boiling Point

Some conversions of the same measurement system …

Metric

1 m/s	3.6 km/h
1 tonne	1,000 kg

Imperial

1 foot (ft)	12 inches (in)
1 yard (yd)	3 ft
1 chain (ch)	66 ft
1 mile (mi)	5,280 ft

Abbreviations:
1 foot = 1 ft = 1’
1 inch = 1 in = 1”

9 Glossary of OHW & Related Terms

The following is a list of common and colloquial terms used in Sydney's OHW system.

Some of these terms had already been established, so I use them here as it made my job of describing them a bit easier. However, many more terms have been added in this document to make it more comprehensive.

The *Reference* column includes likely key places where more information is provided for the *Term*, more than is given in the *Description* column below.

The most common reference is to a particular section in this document, and if so, it shows: *numbered heading – subheading* (if applicable) – *page number*.

But it could also include reference to various *Standards* or *Guidelines*.

I've tried to primarily make a reference to a Section in this document, but it may not be the only location in this document that contains relevant details. In any case it should be a good starting point.

Term	Description	Reference
1500V Authority	A form listing the parts of the OHW, by Section and Subsection, to be taken out of service for alteration or maintenance.	
Acetal Copolymer	An advanced type of plastic insulating material that has high mechanical strength and electrical properties. Has been used in projects for Sydney's system since ~ 2004, in insulating pads and ferrules, & for isolating steel bolts when connecting steel brackets to concrete structures (containing steel reinforcing).	*5.1.18.2* – page *745*.
Actual Bay (or Span)	Bay (Span) length as measured on the ground and not determined from the arithmetic difference of the two structure support locations. The precise distance is from catenary support point at one location to the next catenary support point.	*3.1.0.3* – page *72*, *3.1.1.4* – page *100*.
Adverse Condition (Adverse Wind Load Condition)	This is a check that there is sufficient radial load from the contact wire when registered by a span, to hold the weight of a pull-off arm in place, as wind blows against the radial load. The condition is Contact Radial Load – Wind Load > 250N.	*5.1.23.8* – page *768*.
AirDrop (program)	A computer program written in the Fortran language, that determines OHW dropper lengths and positions for overlap (airgap) bays only in regulated OHW. The program runs on MS-Dos.	*3.1.3.5* – page *162*.
Airgap	An "overlap" in the OHW which is electrically fed from a substation or sectioning hut. An airgap involves 2 electrical sections and is often referred to as a "feeding airgap". This is an old term that is not used much these days. See also "overlap", specifically "*feeding overlap*".	*3.5* – page *488*.
Alive	A conductor is said to be "*alive*" or "*live*" when it is electrically energized.	*2.5.2* – page *40*.

Along-track Wire Movement	In a regulated OHW system, this refers to the movement of the OHW conductors due to expansion or contraction with temperature (hot and cold respectively). Regulated OHW supports are required to allow this movement to take place unimpeded.	*2.5.4* – page *45*.
Anchor	The point where the contact and/or catenary is terminated and held at a structure, so that the conductor can take its full applied tension.	*3.4* – page *432*.
Anchor Bay (or Anchor Span)	That bay (span) between the anchor location and the next OHW support location in that wire run. There are 2 anchor bays per wire run – one at each end. See also *Anchor Pennant*.	*3.5.0.4* – page *492*.
Anchor Pennant	The OHW conductors in the anchor bay.	*3.5.0.4* – page *492*.
Approved Rail Level	Design height of the lowest rail of a track.	*6.2.1.8* – page *867*.
Arm	See "pull-off arm". Also known as "registration arm", "steady arm".	
AS Anchor Structure	A portal structure designed to anchor fixed-anchored OHW runs on its bridge directly above the relevant tracks. Most often used at each end of a single overlap bay, with no need for anchor pennant bays.	*3.3.3.4 – "AS" Anchor Structure* – page *429*.
Auxiliary Catenary	In the compound OHW system installed in the Blue Mountains, this is an additional smaller catenary wire located below the main catenary wire. It is used to help improve the current rating and voltage regulation of an OHW system, and improve the interface with pantographs travelling at speed under temperature extremes (particularly hot temperatures). Working downwards, the main (327mm²) catenary supports the (179mm²) auxiliary catenary which then supports the (193mm²) contact wire.	*4.1.2 – Conductors* – page *636*.
Auxiliary Feeder (A/F)	An additional catenary wire, usually the same size as the main catenary and installed to the side, but it does not support the contact wire. It is used to help improve the current rating and voltage regulation of an OHW system. It is regularly connected to the main catenary using auxiliary feeder jumpers (AFJs).	*3.1.1.5 – Location of Auxiliary Feeders* – page *114*. *3.2.7* – page *385*.
Auxiliary Feeder Jumper (AFJ)	A stranded copper wire that connects the auxiliary feeder to the main catenary at regular intervals (typically every 3rd or 5th bay or so). The wire size is usually that of the main catenary.	*3.1.12* – page *231*.
Back-to-Back Cantilever Arrangement	A cantilever installed on both main faces of a drop vertical or mast that's installed between tracks. This minimises costs and often helps to balance out the applied OHW weight and possibly radial loads on the mast or drop vertical.	*3.3.0.4* – page *392*.
Ballast	The crushed rock / blue metal base for track sleepers to rest on.	*6.2.1.3* – page *862*.
Bay (Span)	Distance between two adjacent catenary support locations (not pull-off locations) in a particular OHW run.	*2.3.1* – page *27*. *2.5.7 – Types of OHW Bays* – page *47*.
Birdcage (a wire)	If a multi-stranded wire is held at one end and rotated axially against its direction of lay, the strands can become loose. This	

	can open up gaps between the various strands – termed "Birdcaging" the conductor.	
Blowout	The lateral movement of the contact (or catenary) wire caused by wind (at usually 130km/h). The value of blowout increases with the square of the bay length, and the maximum amount of blowout is at mid-bay (though this may not be the maximum contact offset in a bay). Contact blowout is normally taken into account during design to ensure "pantograph security" within the bay.	*2.3.1* – page *27*. *3.1.2.5* – page *136*.
Bond	A solid electrical connection of a wire to a metal structure, in order to either eliminate potential difference or minimise electrical resistance at the connection (so as to pass heavy current).	*3.12.0.5 – The Term "Bonding"* – page *603*.
Bonding	In a d.c. OHW system, this term refers to the electrical connection of certain parts of the OHW system to the negative 1500V return ("rail") for purposes of electrical protection in the case of a fault. This can be done using a spark gap in series, or sometimes without one. Do not confuse Bonding with "Earthing" (which is more relevant to the a.c. electrical system).	*3.12* – page *598*.
Bonding Cable	Typically, this is a 95mm² or 120mm² copper cable, covered in Black PVC insulation or the like. 16mm diameter steel bonding cable has been used in high theft areas (coloured orange?). It is used for electrically connecting (bonding) steelwork that OHW fittings attach to, to rail (usually via a spark gap). In this way, should the structure liven up due to failed insulation or other, it provides a direct means of completing the circuit, causing high current to flow and tripping the d.c. circuit breaker/s supplying the power, thus rendering the steelwork safe. Bonding cable is usually not run under any significant tension.	*3.12.0.5 – Bonding Wire or Cable* – page *610*.
Bonding Wire	Bare 95mm² hard drawn copper wire (uninsulated) that is usually run under tension so as to span great distances unsupported. This can be used to connect between successive OHW structures and using a single spark gap in certain bonding schemes, and thus save on material costs, keeping the hazard out of harm's way, etc.	*3.12.0.5 – Bonding Wire or Cable* – page *610*.
Boom	See "portal bridge". See also "horizontal boom".	
Box Culvert	A tunnel way under the track for water drainage, cattle, etc.	
Bracket	An adjustable structural fitting that connects OHW components to a support mast or drop vertical. E.g. jib support bracket attaches the cantilever pipe bottom end to the mast and allows it to pivot.	*3.2.0.3* – page *264*.
Brass Bar	An alternative to a "Ramset Nail", for installing in rock, brick, etc. Acts as a Track Control Mark reference point for determining design track position and/or OHW support & registration component location.	*6.2.2* – page *876*.
Bridge	Portal bridge – the horizontal beam of a portal structure – see also "overline bridge", "underline bridge".	*3.3.3* – page *418*.
Cable	A length of insulated conductor. In OHW the cable only needs to have a single core (for dc). However, HV cables often have three cores, insulated from each other and from the outside (for 3 phase electricity). The insulated conductors may	*2.5.1* – page *39*.

	or may not be provided with an overall mechanical and/or further insulating protective covering.	
Cable-to-Aerial Termination	The configuration of equipment used for terminating the end of one or more 1500V cables and providing a more flexible bare aerial feed to the nearby OHW conductors.	*3.8.0.3 – Cable-to-Aerial Termination* – page *568*.
Camber	The hog of a portal bridge that becomes flat when loaded, thus maintaining good aesthetic appearance.	*3.3.3.4* – page *418*.
Cantilever	A triangular support frame assembled from galvanised steel components, including tubes and chain links, which is mounted on a mast or drop vertical, to support & register the OHW conductors.	*3.2.1* – page *285*.
Cantilever Coding	A group of symbols shown on OHW layout drawings that define the OHW support & registration equipment to be erected at a given location. Each cantilever code refers to the support of an OHW run for one track at one location.	*3.2.1.5 – "Mark-1" Cantilevers* – page *306*.
Cantilever Bridge or Structure	See "Way and Works Cantilever".	*3.3.3.4 – Cantilever & Nose Structure* – page *424*.
Catch Points	A permanently installed set of points, often sprung open in the direction opposite to normal train movements, and intended for derailing a rail vehicle which is moving contrary to signals.	*6.2.1.13* – page *871*.
Catenary (Caty)	The uppermost wire in an overhead wiring system. A stranded hard-drawn bare copper (or steel) conductor that hangs in the shape of a catenary. Its purpose is to support the contact wire and to act as a conductor to help supply electric power to trains. . It is supported over the track at intervals (bays) from various types of support structures. *Simple Catenary* – comprises a contact wire supported from the catenary wire through regularly spaced droppers. *Compound Catenary* – comprises a contact wire supported from the auxiliary catenary above, which is in turn supported from the catenary wire above.	*3.1.1* – page *100*.
Catenary-to-Contact Feeder	See "in-span feeder".	
CCalc (program)	A computer program written by Sydney's Railway Electrical Design Office in the Fortran language in 1985, that calculates all construction information needed to allow staff to accurately install Mark-2 OHW cantilevers. This program is still producing calculations for all new cantilevers being installed throughout the electrified network (even after 30 years of service!). Runs on MS-Dos.	*3.2.1.5 – The "CCalc" Computer Program* – page *325*.
Centre Throw	The additional lateral space taken up at the centre of a rail-mounted vehicle (midway between bogies) when traversing curved track. This additional space must be taken into account for gaining suitable clearances to nearby objects, such as station platforms and awnings, tunnels, etc. See also "End Throw".	*6.3.1.2* – page *883*.
Chain Block	A portable construction tool used for pulling and adjusting wires under tension and lifting other loads. It uses a continuous length of chain and is operated by a lever arm and ratchet. Also referred to as *Come Along* or *Tractel* (which is the common commercial name of such device).	*Figure 626* – page *800*.

Chainage	A survey term used for measuring a straight line distance. Distance was in chains (1 chain = 66ft = 20.117m).	
Channel	A "C" shaped steel member. A standard steel section.	*3.3.0.5 – Double Channel (DC) –* page *398*.
Clamp	A device that mechanically and/or electrically connects one OHW component to another. There is a multitude of types of clamps used in the OHW system. Examples: *Feeder (or Parallel) Clamp* – A piece of hardware used to clamp 2 ("double clamp") or 3 ("triple clamp") parallel wires together for electrical feeding and/or mechanical connection. E.g. Fitting 54/24 (270 / 270mm² double clamp), Fitting 54/49 (90 / 270 / 90mm² triple clamp) *Pipe Clamp* – A piece of hardware used to attach various types of components to a cantilever jib (pipe). *Snail or Strain Clamp* – A piece of hardware used for terminating a catenary wire. *Suspension Clamp* – A piece of hardware used to support a catenary wire in a hanging arrangement. *Catenary Clamp* – A type of clamp that connects to the catenary and holds a dropper in place.	*5.1.20.2 – Clamp Connection –* page *753*.
Clearance – Minimum Electrical Clearance	For the 1500V dc OHW system, a *minimum electrical clearance* of 150mm is normally required between parts that are energized at +1500V and those at earth or -1500V (rail return). See also "*Electrical Clearance*".	*2.6 – Minimum Electrical Clearance* – page *55*.
Cleat	A fastening item. A means of fastening a steel bracket to a structure by clamping around the structure instead of drilling into the structure and bolting. The bolts used on cleat arrangements apply the clamping force. There is a variety of old railway cleats available (with Fitting No's). Alternatively, a typical commercial cleat for OHW work is the "Lindapter" B20L (for 20mm bolt). See *Lindapter*.	*5.1.20.2 – Cleat Connection –* page *751*.
Clipping-Up	The task of sagging a catenary wire at its correct tension, then clamping it at the suspension supports, allowing the installation of droppers within each bay ready for connecting the contact wire/s.	*5.2.3* – page *798*.
Closedown	The planned closing of the train system in a defined area in order to carry out OHW construction and/or maintenance activities. Closedowns normally occur on weekends to reduce the inconvenience to the travelling public getting to and from work on Monday to Friday. However, closedowns can occur any time if required. OHW works are normally carried out in conjunction with other important works to track and signalling infrastructure, etc. and may take more or less precedence. Sometimes closedowns occur at periods of public holidays, including Christmas and New Year period, as this helps to get much more work done and inconveniencing fewer people.	*5.2.3* – page *798*.
Collection	The action of the train's pantograph picking up current from contact wire/s. (Current collection)	*6.3.2* – page *884*.
Collector Strip	A replaceable strip of carbon, copper, aluminium, stainless steel etc. on the top of each pantograph pan which rides under the contact wire.	*6.3.2* – page *884*.

Cologne Eggs	A type of insulated rail support, oval in shape, and located regularly between the sleeper and rail. This device is designed to reduce the noise and vibration caused by passing trains. They are usually employed in areas where generated sound and vibrations are to be kept to a minimum, such as inside tunnels, stations, air-space developments, etc. Because of their thickness, a direct conversion to cologne eggs may reduce the contact height, which therefore needs to be checked out for suitability.	*6.2.1* – page *860*.
Come-Along Clamp	A tool for temporarily gripping catenary wire under tension without damage to the outer strands. This allows the wire to be moved along to a new position. See also "Chain Block", "Tractel" and "Tirfor".	*Figure 626* – page *800*.
Conductor	Anything that will conduct an electric current. OHW uses mostly copper as the conductor in the catenary, contact, auxiliary catenary, in-span feeders, etc, which are all intended to carry heavy electric current to and from trains. The contact wire sometimes has alloys added to copper that promote a particular character.	*2.3.1* – page *27*.
Conductor Equipment	The first category of equipment in this OHW equipment structure.	*2.3.1* – page *27*. *3.1 – Conductors* – page *69*.
Conductor Data Sheet	Some old tables listing all standard OHW conductor sizes and their various characteristics, including stranding makeup, weight per metre, diameter, wind loading, breaking load, etc. Were referred to as documents "T1" and "T1A". The prefix "T" probably referred to 'T'ransmission Lines, and OHW shares some of these conductors.	*3.1.0.5 – Wire Sizes* – page *86*.
Cone Splice	A device for joining wires. It has a wedge-shaped cone with internal serrations that passes over the conductor and grips this when installed into a mating body with the same conical taper. The more tension applied through the device, the stronger the grip onto the wire. Some devices are rated for carrying the heavy catenary current, but older devices require a wire bridge installed over the splice to carry most of the current instead.	*3.1.9 – Cone Splice* – page *220*.
Constant Tension	Refers to tension regulated conductors. This is normally provided by weight tensioners, but even gas tensioners and spring tensioning devices have been used in the past.	*2.5.3* – page *41*.
Contact Clip	A clip that connects the contact wire to the dropper. Various clips exist, and can be fastened onto the contact wire by a wedging nail or bolted connection. The current standard contact clip (fitting 95/30) has a bolted connection, that is suitable as a replacement for all older contact clip arrangements.	*3.1.3.4 – Dropper Make-up* – page *156*.
Contact Separation (Spacing)	The horizontal distance between the 2 contact wires in a twin contact system. This is normally 150mm in the open, and 50mm in tunnels (to suit using the superior "delrin bar" dropper arrangement). There are other special cases e.g. in overlaps, and in areas where droppers are less than about 300mm long. Twin catenary / twin contact systems require 150mm contact separation.	*3.1.2.5 – The Advantages of Twin Contact* – page *149*.

Contact Wire	The wire with which the pantograph is designed to make contact. The contact wire is a grooved solid copper or copper alloy conductor that is normally suspended from the catenary by droppers. Its purpose is to supply power to and from trains via pantographs which slide along its underside. Contact wires are made of Hard-Drawn Copper, Tin-Bearing Copper or Cadmium Copper (which is no longer manufactured), depending on the tensile strength requirements.	*3.1.2* – page *117*.
Contact Wire Gradient	The average slope of the contact wire between two OHW supports locations relative to the track. Typical limits for contact wire gradient used to be: 1:300 for fixed-anchored OHW, and 1:500 for regulated OHW. These days, track speed is also taken into account which can provide a better overall outcome for train running. Refer to the Electrification Standard.	*3.1.2.5 – Contact Ramp Rate* – page *141*.
Contact Wire Height	The height of the underside of the contact wire above mean rail level, when not uplifted by the pantograph. A standard contact wire height is set for each project, e.g. 5.0m in the open route; 4.75m inside most tunnels.	*3.1.2.5 – Contact Height* – page *139*.
Contact-Only System	An OHW system without a catenary wire, primarily used on track where train speeds and current requirements are low. There have been contact-only systems in both regulated & fixed-anchored (currently used at a number of Country Platforms at Central Station).	*Regulated:* *4.2.9* – page *700*. *Fixed-Anchored:* *4.1.8* – page *668*.
Coplanar	Being on the same plane surface as another item.	
Creep	The on-going permanent stretch of wires that can take place under high mechanical tension and over long periods of time. Notable creep mostly occurs in the contact wire – the multi-stranded catenary wire seems to exhibit virtually no creep (probably because each smaller strand is more effectively work hardened across its cross-sectional area during manufacture). Hard drawn copper contact in a regulated is often the biggest culprit for notable creep.	*5.1.16.1 – Creep* – page *733*.
Creepage Path (Creepage Distance)	The shortest path (distance) across the surface of the insulator's insulation between the live and dead conductive metal ends.	*2.9* – page *62*.
Crosby Clip	A U-bolt clamp (fitting 463/21) intended for connecting 90mm² HDBC wire, either joining 2 wires together or the same wire turned back onto itself (e.g. around a thimble).	*3.2.0.3 – U-Bolt Clamp* – page *261*.
Cross-span	A stranded steel or copper conductor which crosses the track at about catenary or contact level, and which is used to restrain the catenary or the contact.	*3.2.0.3 – Cross-Span Wire* – page *260*.
Cubic Parabola	The description of the fundamental formula for determining transition spirals on tracks ("transitions"), when changing from one track radius to another.	*6.2.1.9* – page *868*.
Curve (Track Curvature))	Relating to Track: *Vertical curve* – the vertical curvature of the track forming a dip or a crest in the track. *Horizontal curve* – curvature of a track in plan view. *Transition curve* – a curve of increasing track radius that connects from a curve to a tangent or from a curve to another curve of different radius.	*6.2.1* – page *860*.

	Inside curve – a reference to something being on the inside of the track curve, i.e. the side of the track closest to the centre of radius. E.g. a mast on the inside curve. *Outside curve* – a reference to something on the outside of the curve, i.e. the side of track further away from the centre of radius.	
DCCB	"D.C. Circuit Breaker". This is a high speed electrical circuit breaker that can interrupt many thousands of amps d.c. in 10s of milliseconds, to isolate a fault on the electric traction system. Typical circuit breaker settings are around 4,000A to 6,000A. This circuit breaker can also trip on "rate-of-rise" – if the fault current rises quickly enough, the DCCB circuitry knows that it's likely a fault and does not wait until the full fault current is reached, instead tripping the circuit without getting to the large currents and possibly saving the equipment causing the fault from significant damage.	*6.1.1* – page *856*.
Dead	The term used to refer to the state of electrical equipment being isolated from electrical supply and earthed for safety. Usually applies to ac equipment. (*Note:* the OHW system uses the term "Isolated & Rail-Connected" to achieve the same state.)	*2.5.2* – page *40*.
"Dehn" Spark Gap Module	A spark gap protective device that recovers from a.c. transients (such as lightning), but shorts out to d.c. power faults, as required to protect a particular asset. This device had been successfully trialled on the network in 2011/12 at Katoomba etc. in the Blue Mountains (where lightning strikes are a constant problem with the normal spark gap modules). They are approved for use in the electrified network especially in lightning prone situations or where access is difficult. Refer to drawing EL 0191530.	*3.12* – page *598*.
Derailer	A device that is clamped to the rails as a temporary measure to deliberately derail a vehicle in certain circumstances– performs as catch points.	*6.2.1.13* – page *871*.
Design Criteria	The fundamental design values upon which a particular design of OHW is based. Includes catenary and contact wire sizes, tensions and heights, maximum blowouts with maximum wind speed conditions, etc.	*3.1.0.5* – page *86*.
Down track	A track reference, defining a track where most train travel is intended to head *away from* Sydney. (See "Up Track" for the opposite direction)	*6.2.1.1* – page *860*. *2.5.13* – page *54*.
Drop Vertical	A vertical length of U.C. section or other steel frame which is fixed to the bridge of a portal. The drop vertical is used (similarly to a mast) to support one or more cantilever or pull-off arrangements. Drop vertical can be of single (DS) or twin (DT) variants. Drop verticals installed from a multi-track portal is a most practical and cost effective way for supporting regulated OHW for these tracks. Drop verticals can also be laterally adjusted along the portal bridge if required.	*3.3.3* – page *418*.
Drop Vertical Length & Position Table (Spreadsheet)	A spreadsheet program developed by Sydney's Railway Electrical Design Office, that documents the OHW design requirements of drop verticals, including their length and accurate placement relative to serviced track, at each portal	*3.3.3.4 – Drop Verticals* – page *422*.

	location. This is input for subsequent Civil Design of these structures. Runs on MS Excel.	
Dropper	A small diameter (5 – 6mm) solid copper wire which connects the contact to the catenary by means of clips. Droppers support the weight of the contact wire and their lengths set the running profile of the contact wire (e.g. for presag). They are spaced at set intervals in a bay and are of varying lengths to suit the catenary curve.	*3.1.3* – page *153*.
Dropper Clip	The small fitting for connecting a dropper to the top of the contact wire (with wedge or bolted connection).	*3.1.3.4 – Dropper Make-up* – page *156*.
Dropper Loop	The two parts of a typical dropper (upper & lower loops) can telescope inwards whenever the contact wire is lifted and so prevents buckling and eventual fatigue, which may occur with a single piece dropper.	*3.1.3.4 – Dropper Make-up* – page *156*.
Dropper Nail	A tapered brass wedge driven between the dropper clip and the groove in the contact wire to hold the contact wire to the dropper assembly. This is an old arrangement that has been superseded by a universal contact clip using a bolted connection.	*3.1.3.4 – Dropper Make-up* – page *156*.
Dropper Programs	Computer programs developed to help determine the length and position of each dropper in each bay of OHW. More recent programs also generate all necessary dropper fittings for each dropper assembly.	*3.1.3.5 – Dropper Programs* – page *170*.
Droppering	The process of spacing the droppers along the catenary in a bay and attaching the droppers to the catenary.	*3.1.3.4 – Dropper Spacing* – page *155*.
Earthing	The connection of a piece of a.c. electrical equipment to the general mass of earth though an earth rod or similar. This is not to be confused with "Bonding" (which is more relevant to the d.c. supply system).	*2.5.10* – page *52*. *3.12* – page *598*.
Earthing Cable	This cable is used for earthing a piece of equipment, and would typically be 70mm² copper (the actual size required needs to be confirmed by the designer). This cable must not be confused with "Bonding cable" (which is black and connects to the traction return circuit). Earthing cable is identified by green/yellow insulation.	*3.9.0.3* – page *585*.
Earth Mat	A buried grid covering a fairly large area for substations where low earth resistances are required.	
Earth Rod	A metal rod with earth wire connection to disperse currents into the ground for safety.	*3.9.0.3* – page *585*.
Earth Wire	A cable (usually with green/yellow insulation) connecting a piece of equipment to the general mass of earth.	
Earth, Earthing	The process of directly connecting a piece of equipment to an earth rod or similar. The intention is to make the piece of ac equipment safer. For dc it helps surge arresters to dissipate lightning strikes (to earth).	*3.9.0.5 – Lightning Path to Earth* – page *588*.
Earthed	Connected to the conducting mass of the earth, in such a manner as will ensure at all times an immediate discharge of electrical energy without danger. (Not to be confused with "Rail-connected" for OHW purposes.)	*2.5.10 – "Bonding" is Not "Earthing"* – page *52*.
Electrical Clearance	The clearance required between live 1500V equipment and other objects, so as to ensure adequate safety. *Passing Clearance* – air clearance between live parts of either the travelling vehicle (pantograph) or OHW system and	*5.1.24* – page *769*. *2.6 – Minimum Electrical Clearance* – page *55*.

	earthed parts of the fixed structures during the passage of the train. *Static Clearance* – air clearance between live parts of an OHW system and earthed parts of a fixed structure, when the OHW is not influenced by a passing pantograph.	
Electrified Area	The extent of railway provided with overhead wiring for running electric trains.	*1.7.1* – page *13*.
Element	A part of a cantilever coding reference. There are up to 5 elements in the coding of Mark-1 Cantilever system (using the "Mast" computer program), and up to 9 elements in the Mark-2 Cantilever system (using the "CCalc" computer program). E.g. "-1ALPV*" has 7 elements.	*3.2.1.5 – Cantilever Coding for Mk-1 Cantilevers* – page *310*. *3.2.1.5 – Cantilever Coding for Mk-2 Cantilevers* – page *320*.
End Throw	The additional lateral space taken up at both ends of a rail-mounted vehicle when traversing curved track. This additional space must be taken into account for gaining suitable clearances to nearby objects, such as station platforms and awnings, tunnels, etc. See also "Centre Throw".	*6.3.1.2* – page *883*.
Equalizer Bar	A fitting used to divide the tension from a tension regulator between 2 wires in some given ratio, e.g. for Gosford to Newcastle OHW system, 33kN from the tension regulator divides into 16.5kN for the catenary wire and 16.5kN for the contact wire. The equalizer bar can rotate to ensure the same ratio of tensions, even if wire creeps over time (until the bar binds).	*3.4.2.3 – Equalizer Bar (Yoke Plate)* – page *451*.
Equipotential Operator's Platform (or Mat)	A steel mat that a switch operator stands on when operating a 1500V switch. The switch operating handle and mat are electrically connected, which is intended to avoid the risk of the operator receiving a shock if an electrical fault occurs during switch operation.	*3.7.0.5 – Equipotential Operator's Platform* – page *551*.
Eye Bolt	A length of threaded rod with an eyelet at one end. *Example:* An eye bolt is used in weight tension regulators to help guide the weight stack up and down the mast. In this situation, the eye bolt is threaded into one weight which is prepared with a tapped thread for this application.	*3.4.2.3 – Guide Rod Assembly* – page *451*.
Fasteners (for OHW)	Various types and methods exist for fastening parts together for use in OHW.	*5.1.20.1* – page *747*.
Fasteners for Bonding Connections	Because of the extremely high mechanical forces developed under high current fault conditions and the consequent need to make a solid connection, bonding cable is normally connected to a piece of steel equipment by using suitably sized bolts.	*3.12.0.4* – page *601*.
Fault Level	The amount of current likely to flow as a consequence of a short circuit placed at a particular location in the electrical network. For the 1500V dv system, this is typically measured in kiloamps (kA), e.g. up to 50kA or so.	*1.6* – page *12*. *3.8.0.4 – Feeder cable* – page *572*.
Feeder Jumper ("FJ")	A flexible wire that connects from catenary to catenary of different wire runs. The wire is normally of the same size as the catenary, and is bent into a "U" shape to allow regulated OHW to move unrestricted with temperature changes. It provides continuity of current flow between separate tension	*3.1.12* – page *231*.

	runs of OHW. Commonly used at sectionable overlaps and at turnouts.	
Feeding Loop (Feeder Loop)	An arrangement formed in the catenary that allows the catenary wire to come out of mechanical tension so that a high current electrical connection can be made to the catenary.	*3.8.0.5 – Catenary Feeding Loop* – page *575*.
Feeders	Conductors which supply electric power to the OHW, or augment the power carrying capacity of the conductors in a supply system. *Aerial Feeders* – these connect from switches or cable feeds to the catenary wire for transmitting power to and from the OHW system. *Auxiliary Feeders* – these bare conductors run parallel to the OHW catenary wire (& usually the same size), to help boost current rating and/or lower circuit resistance for improved DCCB settings. *In-Span Feeders* – these carry current between the catenary and contact wires within each bay of the OHW run.	*3.8.0.3 – Aerial Feeder* – page *569*. *3.1.0.5 – Auxiliary Feeders* – page *90*. *3.1.4 – In-span Feeders* – page *183*.
Feeding Airgap or Feeding Overlap	An airgap. Also known as a "feeding overlap". An overlap that has electrical feeders connected for transmitting electrical power from a substation / sectioning hut / switch, to the OHW.	*3.5.0.2* – page *489*.
Ferraz Unit	An electronic device that performs the functions of a spark gap, but also can send a supervisory signal to the Electrical Operating Centre to alert on its operation and current status (opened/closed). It is contained (sparkless), so has been used in the past at coal and wheat unloader buildings, etc. (when electric freight trains used to operate in the system), where the atmosphere can be explosive. They can also be used where a structure or other utility can't tolerate electrolysis currents for long time, e.g. gas pipelines, etc. A "closed" indication normally initiates some fairly immediate corrective action in the field. There is a significant cost that needs to be acknowledged, for the necessary power supply and SCADA communications connections.	*3.12.0.5 – Types of Spark Gaps* – page *610*.
Fitting	A manufactured part used to attach one item to another in the OHW system. The term "fitting" includes all brackets, insulators, and the droppers but not the supporting structure, catenary or the contact wires. Most OHW fittings have an OHW fitting number for ready reference.	*5.1.5* – page *706*.
Fitting Number	OHW fitting numbers are given to most OHW fittings to allow ready identification and manufacture. *OHW Fitting No.* – Consists of up to 3 digit number, a "/" then up to 2 digit number, e.g. 954/52, 61/2. *Transmission Line Fitting No.* – Consists of a "T", up to 3 digit number, a "/" then up to 3 digit number, e.g. T11/17.	*5.1.5* – page *706*.
FixDrop (program)	A computer program developed by Sydney's Railway Electrical Design Office and written the Fortran language, that determines OHW dropper lengths and positions, for bays of fixed-anchored OHW. Runs on MS-Dos.	*3.1.3.5 – Dropper Programs* – page *170*.
Fixed Anchor	An anchor that locks the catenary and/or contact wires at the end of a run of OHW.	*2.5.4* – page *45*.

	In regulated OHW – This is the opposite end of the wire run to where the tension regulator is installed. On the OHW Layout it is given the symbol "F" (inside a square). *In fixed-anchored OHW* – This is simply an anchor that appears at both ends of the wire run. On the OHW Layout it is given the symbol "F/A" (inside a rectangle).	
Fixed-Anchored OHW (F/A)	An OHW system where the catenary and contact wires are rigidly anchored at both ends of a wire run. In a fixed anchor system, there is no net wire movement along the track due to temperature change. Instead, tension changes due to temperature variations, cause the catenary of each span to sag more (when hot) or sag less (when cold), so causes the contact wire to fall or rise (respectively) at the middle of each span.	*2.5.3* – page *41*.
Fixed Mid-Point (FMP)	A location in a regulated OHW run where the catenary wire is locked from longitudinal movement. This allows a tension regulator to be placed at both ends of the wire run (thus forming 2 tension lengths), and can effectively double the allowable wire run length to about 2km. (Limit of tension length is typically 1,000m.) A bridle in each direction, from catenary to contact at the FMP, is also needed to prevent contact wire movement. It may be convenient to use an overline bridge as the fixed mid-point, i.e. attaching the catenary to the suspension angle (L-Iron or T-Iron) or bridge face or girder. An FMP anchor need not be at the exact middle of the run – its position is partly governed by the calculated tension loss at that point.	*3.4.5* – page *478*.
Fixed Mid-Point Bridle	The span from anchor (mast) to catenary clip at a fixed mid-point location. This locks the catenary from along-track movement, allowing the tension regulators at both ends of the wire run to perform correctly. There are 2 mid-point bridles associated with a fixed mid-point arrangement – one to lock the catenary in each direction – to Sydney and to country. (Catenary-to-contact bridle wires then lock the contact wire relative to the catenary.)	*3.4.5.5 – Anchor Bridle to Catenary* – page *482*.
Fixed Mid-Point Bridle Anchor	The mast, normally with a guy, that takes the strain from the mid-point bridle.	*3.4.5.5 – Anchor Bridle to Catenary* – page *482*.
Flange	In an "I-Beam" (or Universal Column) steel structure, the flange is the steel face located at the top and bottom of the "I" section. When an OHW cantilever is installed onto a 250 U.C. mast, the mast attachment brackets are installed onto the flange, as this orientation has the most bending strength to resist the applied OHW loads.	*3.3.0.5 – Common Structure Sections* – page *395*.
Floating Section	An insulated section of OHW conductors with no deliberate electrical connection to a power supply or earthing system. Floating sections are not normally permitted in the electrified network. (Exceptions are at the entry to car sheds to help control pantographs leading into the shed.)	*2.5.2* – page *40*.
FMECA	Acronym for "Failure Modes, Effect & Criticality Analysis".	*5.4.6 – The Technical Maintenance Plan for OHW* – page *821*.

Footing	The foundation of a mast or portal leg. The footing is normally concrete which helps provide a stable foundation for the structure.	*3.3.0.5 – Footing* – page *405*.
Forked Collar Socket	A quick and simple means of terminating a conductor using a wedging collar mechanism to lock the conductor in place. Currently Sydney's OHW System has a number of approved forked collar sockets for contact wires and catenary wires.	*3.1.8.4 – Forked Collar Socket* – page *216*.
Galloping	Conductor galloping is the wild movement of conductors especially towards mid-bay, resulting from high cross winds that strike the OHW conductors. Especially noticeable if the movements are relative to each conductor. Related to natural frequency of the system and can be dampened by suitable methods, including avoidance of common bay lengths together.	*3.1.2.5 – Dynamic Oscillations ("Galloping")* – page *141*.
Gantry	Another term for portal, more often describing a portal for signals.	*3.3.3.1* – page *418*.
Gin Wheels (or Ginny Wheels)	A single pulley device that's temporarily installed to support the catenary at each support location when running a new catenary wire. The pulley allows the installed catenary wire to settle at its natural position in the run, then the catenary can be removed and installed in its permanent support location (locked off). The pulley is installed at approximate catenary height. It has a gate that opens to accept or remove the catenary, and is normally made of softer aluminium so as to avoid damaging the outer catenary strands when handled.	*5.2.3* – page *798*.
Grout	A fine cement mixture for packing in small spaces e.g. around rock anchors and base plates at foundations. When dried, it helps to spread any applied mechanical load more uniformly to ground.	*3.3.0.5 – Footing* – page *405*.
Guard Rail	Lengths of track rail installed between the normal rails of a track at crucial locations where consequence of a train derailment has a high risk (such as at an underline bridge). The guard rail is intended to help guide the train wheels in case of a derailment, to an area past the crucial location.	
Guide Rod	With weight tension regulators, a weight guide rod is installed on an anchor mast and positioned vertically right next to the weight stack. An eye bolt in one of the weights ties the weight stack to the guide rod while still allowing the weights to move up and down with temperature. The guide rod tries to restrain the weights from moving about under windy conditions.	*3.4.2.3 – Guide Rod Assembly* – page *451*.
Guitar Head	The catenary support plate fitting, shaped like a guitar head, that fits into the top of the cantilever jib pipe, for Type 1 and Type 2 cantilevers. See also "Mushroom Head" for Type 3 cantilevers.	*3.2.0.3 – "Guitar Head" Fitting* – page *287*.
Gunmetal	A copper alloy used in many OHW clamp fittings, mainly to provide a suitable interface with the hard-drawn copper strands of a catenary (or contact) wire. Suitable for high mechanical compressive loads needed for passing heavy current between conductors (to reduce electrical resistance).	*5.1.16.3 – Gunmetal* – page *738*.
Guy	A length of wire rope or solid steel rod that connects one item to another in order to transfer loads and/or restrain relative positions. *Example:* An "anchor guy" connects from	*3.4.0.4 – Guy Arrangement* – page *437*.

	catenary or contact anchor plate on a mast, to a ground anchor at about 45° to horizon.	
Half Moon	An older style dropper fitting, consisting of a "C"-shaped brass casting which slides onto the taper on a corresponding shell so as to connect the upper dropper to the catenary wire.	*3.1.3.4 – Dropper Make-up* – page *156*.
Half-Splice (Contact Half-Splice)	A termination fitting made from gunmetal, designed to grip a contact wire at one end, and connect to other tensioning equipment using a clevis fitting at the other end. It is designed to be located close to the in-running contact level, as used in a Type 5 Section Insulator.	*3.1.6.2* – page *199*.
HDBC	Hard Drawn Bare Copper.	*3.1.0.5 – Hard Drawn Copper* – page *86*.
Heel Height	This is the vertical distance between the bottom of the contact wire and the pivot height at the remote (heel) end of the pull off arm. The distance is set differently to suit the radial load; the higher the radial load the smaller the heel height.	*3.2.0.5 – Heel Height* – page *273*.
Heel (of pull-off arm)	The opposite end of the pull-off arm to the contact swivel clamp attachment.	*3.2.0.3 – Pull-off Arm* – page *256*.
Helical Wrap-on	See Wrap-on	
High Voltage (HV)	**Definitions vary**, but generally a nominal system voltage exceeding 1,000V ac or 1,500V dc.	
Hockey Stick	A "J" shaped pull-off arm used in fixed-anchored OHW at restricted locations. It can only be used where there is a small amount of contact radial load.	*3.2.0.3 – Pull-off Arm* – page *256*.
Hog	Contact hog is where the contact wire rises towards mid-bay then lowers at the other end of the bay. The opposite of sag.	*3.1.2.5 –Contact Wire "Hog" & "Presag"* – page *124*.
Hold Down Bolts	Bolt threads in concrete foundations which are designed for attaching the base plates of masts. Typically, there are 4 or 6 bolts, with 2 nuts (one as a locking nut) required per bolt to securely fasten the steel base plate.	*3.3.0.5 – Footing* – page *405*.
Horizontal Boom	The horizontal part of a contact registration assembly used with Type 1A or 2A cantilever construction. This places the pull-off arm on the remote side of the track.	*3.2.1.4* – page *290*.
Horns	*Pantograph Horns* – The bent or angled downwards portion of the pantograph at each end of the pantograph head. These are intended to pick up an adjacent contact wire in a controlled way and bring it onto the top of the pantograph, e.g. a pantograph traversing from crossover into main line OHW often requires this action. *Arcing Horns* – These are generally "V" shaped metal rods that take an established arc and force it upwards, and in the process extending the arc's length until it can no longer be sustained – extinguished.	*6.3.2.1 – Standard Flat Pantograph Head* – page *887*. *3.6.0.5 – Arcing Horns* – page *512*.
HPM Mast	A mast or portal leg with a bottom plate which includes holes for connecting to a formed concrete foundation using several hold-down bolts protruding up from the concrete pedestal. Large galvanised nuts are used to fasten the mast/leg to the concrete pedestal.	*3.3.0.5 – Footing* – page *405*.

Hump Back Split Pin	Special stainless steel pin used at one or both ends of another larger pin (typically 16mm diameter) for securing the large pin in place.	*5.1.21.1 – Discrete Adjustment* – page *754*.
Impedance Bond	A centre tapped coil on an iron circuit that is connected between rails & with the centre-tap connected to substation negative. This device has a high reactance to the ac used in signalling systems, but has very little resistance to the dc of the OHW system. This helps detect the presence of trains for the signalling system.	*6.5.4* – page *922*.
Independent Registration	Is when the catenary and contact wires over each track are supported and registered independently of wiring on adjacent tracks. So, if an incident occurred and the overhead wiring was damaged on one track, the OHW on adjacent tracks should remain intact, allowing trains to still run on those tracks.	*5.6.1* – page *839*.
In-Running (IR) Contact Wire	The contact wire that provides the mechanical & electrical interface with passing pantographs. An overlap bay transitions one in-running contact wire to become out-of-running (OOR) near mid-bay, while the adjacent contact wire does the converse, allowing a smooth pantograph take-up and transition through the bay.	*3.5.0.2* – page *489*.
In-span Feeder (ISF)	Internal feeders in an OHW system that transfer currents between the catenary and the contact wires. They are a multi-strand copper conductor 91/1.12mm (about 90mm^2), and usually appear as a vertical wire with horizontal coil near the base connection to the contact wire.	*3.1.4* – page *183*.
Insulated Knuckle	A knuckle which incorporates an insulator, thus preventing the shorting of adjacent electrical sections. They are used mainly in fixed-anchored equipment, or where the 2 connected wires have little relative movement with temperature in a regulated OHW system.	*3.1.5.4 – Insulated Knuckle* – page *192*.
Insulated Rail Joint (IRJ)	A sectioned track rail with a thin insulating pad installed between the rails and with the rails electrically bridged using an impedance bond. Both rails of a track will have an IRJ at the same location. Required by the signalling system to detect the presence of trains.	*6.2.1.7 – Insulated Rail Joints* – page *867*.
Insulation	Insulation is the provision of some form of electrical isolation so as to prevent electrical continuity. Types of insulation: insulators (including ceramic, porcelain, plastic resin, fibreglass), plastic insulation surrounding the core of energized cables, air, plastic ferrules, etc. Regarding Bonding schemes: *Primary Insulation* – is the main insulation for the 1500V OHW system. *Secondary Insulation* – is smaller insulation in addition to the primary insulation, to help isolate the traction return circuit from local earthing system. *Tertiary Insulation* – is further insulation in addition to the secondary insulation, which may have merit in combating stray currents whilst isolating the 1500V negative return circuit from the local earth system.	*2.9 – 1500V Insulation* – page *62*. *3.12.0.5 – Levels of Insulation* – page *614*.
Insulation Ferrule	Insulation Ferrules are plastic parts that have a "throat" for surrounding and isolating an attachment bolt, and a "collar"	*5.1.18* – page *744*.

	for applying compressive forces in a bolted connection. Typically, there would be 4 ferrules per connection, and they are used to electrically isolate attachment bolts from the surrounding steelwork to prevent stray d.c. leakage currents. They are normally used in conjunction with an "Insulation Pad" to completely isolate the steel plate from the attachment bolts. The electrical isolation in an insulation ferrule can be conveniently tested using a 500V "Megger" or similar high resistance testing device.	
Insulation Pad	An Insulation Pad is typically used in conjunction with "Insulation Ferrules" to electrically isolate one piece of steelwork from another, in order to prevent stray d.c. leakage currents. The Insulation Pad normally has substantial mechanical pressure applied to it as the 2 adjacent structural parts are clamped together.	*5.1.18* – page *744*.
Insulator	Any body or substance designed and provided for the purpose of surrounding or supporting a conductor so as to restrict the flow of electricity to a desired path. *Post Type Insulator* – a rigid insulator which may be mounted vertically or horizontally and which has defined properties in bending, torsion and tension. E.g. fittings 452 and 452/10. *Cycloaliphatic Resin Insulator* – See "Post Type Insulator". Fitting 452/10. *Disc Insulator* – a bell-shaped insulator of glass or porcelain used singly or in strings. E.g. 453/13. *Pin Insulator* – an insulator, usually installed upright and fastened by a pin, not suspended. *Pull-Off or Side Strain Insulator* – intended for connecting the pull-off registration equipment to (with limited tensile loading). These are typically installed next to the mast or drop vertical. E.g. 453/13. *Suspension Insulator* – an insulator or string of insulators which are suspended (placing them in tension). E.g. Fittings 453/13, etc. *Stand-off Insulator* – a solid core insulator with structural strength. *Termination or Strain Insulator* – an insulator or a string of disc insulators used in line with and taking full conductor tension, and installed in nearly horizontal position. E.g. 453.16, 453/17. *Synthetic Insulator* – an insulator made from fibreglass and plastics or epoxy resin.	*2.9* – page *62*. *3.2.0.3 – Insulators* – page *249*. *3.4.0.3 – Termination Insulators* – page *434*.
ISG	A survey coordinate system for recording location information. Stands for Integrated Survey Grid, and applies to New South Wales. It is an older coordinate system that is being replaced by the MGA system. You can tell if it's ISG if the Northing starts with a "1", e.g. on the OHW Layout, North Sydney Station has a Northing of about 1,254,000. (m).	*5.1.31 – ISG* – page *786*.
Isolate	To disconnect from all sources of electrical power supply.	*2.5.2* – page *40*.
Isolated & Rail-Connected	A feeder is isolated from the source of supply and rail-connected to help ensure there is no electrical potential between the equipment connected to the feeder and rail.	*2.5.2* – page *40*.

Jib	Cantilever jib – the inclined strut (pipe), member of a cantilever.	*3.2.0.3 – Cantilever Pipe ("Jib") –* page *286*.
Jib Attachment Height	The height above rail level (or Nail) to the underside of the lower support bracket of a cantilever frame installed on the mast, portal leg or drop vertical.	*3.2.1.4* – page *290*.
Jumper	An internal electrical connection in the overhead wiring system, a short conductor installed to provide electrical continuity. *Feeder Jumper* – an electrical connection from a feeder to the overhead wiring system or the heavy current bridging jumper in an overlap or turnout. (FJ) *Potential Jumper* – a light internal jumper in the OHW (90mm² HDBC) to keep two wires at the same electrical potential. It should never carry significant current. (PJ)	*3.1.12* – page *231*.
Jumpered Overlap	An overlap in which the two separate OHW tension runs are connected with feeder jumpers, which may be removed to provide isolation between the two electrical sections.	*3.5.0.2 – Sectionable Overlap* – page *489*.
KF-ROW (program)	An Excel spreadsheet program using Visual Basic, that is a suite of OHW design tools ("ROW" = Railways Overhead Wiring). It allows for the convenient selection of an OHW system, then provides calculations on sags, temperature/tension, blowout, tension loss, mast spacing charts, virtual spans, and wire data.	*8.3* – page *947*.
Kinematic Envelope (KE)	The extreme profile of rail vehicles in motion, which includes shift of the wheels on the rails, body roll and sway, centre and end throw. This is used to prevent clash with other objects in the rail environment. Often an additional clearance amount is provided to ensure these objects will never be a problem. E.g. KE + 200(mm).	*6.2.1.14* – page *872*.
Knee-brace	The steel member fabricated from angle sections and located at the inside corners between portal legs and bridge, which provides additional structural rigidity. *Wide Knee-Brace* (WKB) – a knee-brace with increased spacing between angle sections, which permits cantilevers to be installed and provides space for cantilever jib movement induced by OHW conductor expansion and contraction.	*3.3.3.4 – Knee-Braces* – page *420*.
Knuckle	Various types of knuckles exist that help connect, or control the movement of, adjacent conductors where they come together. Knuckles can be crossing or parallel, insulated or non-insulated, suitable for catenary-to-catenary or contact-to-contact wires.	*3.1.5* – page *188*.
Lattice Structure	A structure built up from standard steel sections as primary and secondary members. Such a structure is relatively light weight but strong, and is also expensive due to the number of welds required to fasten the numerous steel connections.	*3.3.0.4* – page *391*.
Lead (pronounced "leed")	A length of suitable wire that electrically connects 2 items together. E.g. short leads are used to connect a surge arrester across the cable it's protecting.	*3.9.0.5 – Length of Connecting Leads (Wires)* – page *588*.
Leakage Currents (Stray Currents)	These are dc electrical currents that arise when alternate paths are found back to the voltage source (substation or sectioning hut), rather than all the current flowing by the intended path through the steel rails of tracks. These *stray currents* are	*3.12.0.2* – page *599*.

	mostly unwanted and can give rise to electrolysis corrosion if passing through steel structures, etc. along the way.	
Level Crossing	A right-of-way crossing the track at rail level for pedestrians, vehicles or animals. A raised contact wire height is required for safety at vehicular level crossings. The contact height would typically be such that, in the worst case, there is a 1,000mm vertical clearance to the tallest vehicle passing over the level crossing. Refer to the Standards for latest requirements.	*3.11.0.5 – Types of Signs* – page *596*.
Lindapter	A commercial cleat for fastening 2 steel items together. Typical Lindapter for OHW work is "B20L" (for 20mm bolt), e.g. for clamping a post type insulator bracket onto the flange of a drop vertical. For correct installation, the Lindapter may require one or more "Clipped Washers" (CWs) to ensure the teeth are at the correct orientation. (These are provided by the manufacturer.)	*5.1.20.2 – Cleat Connection* – page *751*.
Live	See " Alive".	
Loaded Tension	This is the catenary tension with contact wire, droppers and in-span feeders installed, when tensioned as fixed-anchored.	*3.1.1.5 – "Unloaded" versus "Loaded" Catenary* – page *108*.
Lug	*Crimped* – A terminal attachment to the end of a wire for an electrical connection using a compression or crimping tool. *Terminal* – a crimped or a soldered piece to terminate a wire for electrical connection.	*3.8.0.3 – Cable* – page *568*. *3.7.0.4 – Switch Terminals* – page *542*.
Mast	A steel universal column (UC); a leg of a steel portal. Most masts used in Sydney's OHW system are 250 UC (250mm × 250mm approx.), and are about 7.5m to 8m tall above ground level.	*3.3.2* – page *416*.
Mast (program)	A computer program developed by Sydney's Railway Electrical Design Office and written in the Fortran language in 1980, that calculates all construction information needed to allow staff to accurately install Mark-1 OHW cantilevers (for Gosford to Newcastle, etc). Runs on MS-Dos.	*3.2.1.5 – The "Mast" Computer Program* – page *312*.
Mast Coding	Same as "Cantilever Coding".	*3.2.1.5 – Cantilever Coding for Mk-1 Cantilevers* – page *310*. *3.2.1.5 – Cantilever Coding for Mk-2 Cantilevers* – page *320*.
MastWood (program)	An adaptation of the "Mast" computer program, that calculates all construction information needed to allow staff to accurately install Mark-1 OHW cantilevers installed on wood poles (for Blacktown to Riverstone, etc). Runs on MS-Dos.	*3.2.1.5 – The "Mast" Computer Program* – page *312*.
Maximum Blowout in Bay	The maximum displacement of the contact wire from track superelevated centreline with the inclusion of wind causing the wire to blowout (typically 130km/h). Limited to ±381mm to ensure "pantograph security". The location of maximum blowout does not necessarily occur at mid-bay.	*3.1.2.5 – Contact Blowout* – page *136*.

Mean Rail Level	The approved design rail level plus half the superelevation. All conductor heights are referenced to the mean rail level.	*3.1.2.5 – Contact Height* – page *139*. *6.2.1.8 – Mean Rail Level* – page *868*.
MGA	A survey coordinate system for recording location information. Stands for Map Grid of Australia, and applies to all Australia. MGA coordinate system is replacing the older ISG system, and is more relatable to GPS, e.g. on some GPS receivers you can select a readout in MGA coordinates or in Latitude/Longitude. In Sydney, you can tell if it's MGA if the Northing starts with a "6", e.g. on the OHW Layout, Chatswood Station has Northing of 6,258,700. (m).	*5.1.31 – Survey Coordinate Systems* – page *786*.
Mid-Bay Offset (MBO) [or Mid-Span Offset (MSO)]	The deviation of the static contact wire from the superelevated centreline of track at half way between the adjacent pull off arms. This is a critical dimension that can help confirm Pantograph Security.	*3.1.2.5 – Contact Blowout* – page *136*.
MinCont (program)	A computer program that is used to determine the minimum contact height in a bay of fixed-anchored OHW under hot conditions. The lowest level of contact needs to still be greater than 4.57m (or 4.42m in certain city underground tunnels). This should be routinely used in certain crucial areas to ensure reliable train running under conditions of extreme heat. Runs on MS Excel.	*3.1.2.5 – Low Contact Height* – page *140*.
Mini Cantilever	A small cantilever for use on portal structures.	*3.2.1.5 – Mini-Cantilevers* – page *297*.
Minimum Contact Height	The contact height needs to be at least 4.57m above mean rail level under the worst-case situation (or 4.52m under special defined circumstances, e.g. some City Underground tunnels). 4.57m is 150mm above the top of train (4.42m).	*3.1.2.5 – Contact Height* – page *139*.
Moving Anchor (M)	See Tension Regulator.	
MTS	Short for Metropolitan Track Strengthening, which was a project set up in the late 1980s to install concrete sleepers throughout the network to provide a more stable track (especially under temperature extremes). This project required the OHW to be adjusted to suit the higher track level due to the thicker concrete sleepers compared to timber.	*6.2.1.4 – Concrete Sleepers* – page *863*.
Mushroom Head	The catenary support plate that fits into the top end of the cantilever jib-pipe for Type 3 cantilevers. See also "guitar head".	*3.2.0.3 – "Mushroom Head" Fitting* – page *288*.
Novasteen	An older insulating material used for insulating pads and ferrules. It is an industrial laminate material combining cotton cloth and phenolic resin, giving it high load bearing characteristics. However, it was required to be sealed from moisture ingress with an appropriate varnish. Moisture ingress would degrade its electrical isolating characteristics, rendering it less suitable for preventing leakage currents.	*5.1.18.4* – page *746*.
No-Load Tension	This is the "Unloaded" catenary tension, i.e. without any contact wire, droppers or in-span feeders that may otherwise increase the tension in the catenary when tensioned as fixed-anchored.	*3.1.1.5 – "Unloaded" versus "Loaded" Catenary* – page *108*.

Offset	This is the horizontal displacement of contact wire from the superelevated centreline of track anywhere in the bay. ("Stagger" generally applies to the offset at the registration point.)	*3.1.2.5 – Contact Stagger* – page *129*.
OHW	Overhead Wiring. The more precise term for Sydney is Railways Overhead Wiring (ROW).	This whole document
OHW Structure Location Number	A unique number, expressed in feet or metres and with a 1 or 2 character prefix, which defines the location of the OHW when measured in chords along the track. Location Numbers are measured from the datum zero (No 12 Platform, Sydney Central Station). Except where specifically designated, the Location Number is **not** the same as the track kilometrage with the same number.	*5.3.3* – page *811*.
OHW Upgrade	The process of renewing the old OHW. This mostly involved also converting from a fixed-anchored to a regulated OHW system for vastly improved performance and reduced ongoing maintenance workload. A big benefit was to end up with twin contact wires in most areas.	*5.6.4* – page *841*.
Out-Of-Running (OOR)	Refers to the contact wire in a position that cannot provide mechanical & electrical interface with a pantograph due to its height. Out-Of-Running contact wire is normally located above the In-Running contact in an overlap bay, and this wire rises further on its way to anchor. (See also In-Running)	*3.5.0.2* – page *489*.
Overlap (O/L)	A configuration of 2 runs of OHW that allows one run to finish and another to take its place, and in doing so provides a smooth, arcless pantograph transition from one run to the next, even at speed. Overlaps can be configured as Feeding, Sectionable or Non-Sectionable. See also "airgap".	*3.5* – page *488*.
Overlap (program)	A spreadsheet program written by Sydney's Railway Electrical Design Office, used to determine the optimal design characteristics of each unique OHW overlap. The program models variables such as bay length, track radius, out-of-running contact heights, twin mast spacing, conductor sizes and tensions, wind speeds, etc., to determine suitable characteristics for the site-specific design of overlaps. Mandatory for all new overlaps. Runs on MS Excel.	*3.5.0.5 – The "Overlap" Spreadsheet Program* – page *503*.
Overlap Arrangement	That portion of the OHW between two anchor structures, where the contact and catenary wires of two wire runs overlap and terminate. This typically takes 3 bays to achieve, although some require 4 bays.	*3.5.0.5 – Overlap Design* – page *498*.
Overlap Bay	That portion of the OHW overlap that has the 2 runs of OHW parallel to each other (typically 250-300mm horizontally apart). At one end there's an in-running and an out-of-running contact and these roles reverse at the other end of the overlap bay. The overlap bay typically has 1 or 2 bays.	*3.5.0.4* – page *492*.
Overline Bridge (OLB)	Any permanent fixed bridge construction over the track.	*6.4.1* – page *902*.
Over-Run Protection	A technique in OHW design that avoids the possibility of pantograph damage due to electric trains entering unwired tracks, and the pantographs rising and striking portal bridges or span wires or causing other damage to infrastructure.	*3.10* – page *590*.

Over-tension	The process of overloading: a) A catenary wire, to quickly settle the lay of the strands. b) A contact wire, to try to remove most initial wire creep. Very little subsequent stretch occurs if the conductor is overloaded by about 50% for at least 30 minutes.	*5.2.3* – page *798*.
PanGauge (program)	A spreadsheet program written by Sydney's Railway Electrical Design Office, that helps determine if structures or equipment installed close to a track are electrically and/or mechanically clear of a train's pantograph. Two tracks can be modelled, and several objects drawn in space. A chart is drawn of the situation, allowing a visual assessment of whether the situation is acceptable or not. (It also gives an idea of clearance to the approximate structure gauge.) Runs on MS Excel.	*6.3.2.3* – page *894*.
Pantograph (abbreviation "Pan")	The current collection mechanism located on the roof of a train. The pantograph pushed upwards, and includes a pair of carbon strips spaced apart that run along the underside of the contact wire/s to collect heavy current to supply the electrical needs of the train.	*6.3.1.1* – page *882*. *6.3.2* – page *884*.
Pantograph Carbon	The strip or a section of the strip of carbon on the stainless steel pan of a pantograph. The carbon greatly extends the life of the contact wire it runs along, while providing a good electrical connection to the contact wire, even at high train speeds. Metallised carbon comes in strips about 30 cm long scarfed at 45°. Single full length carbons are not metallised but made of graphite.	*6.3.1.1* – page *882*.
Pantograph Gauge	The clearance required from surrounding objects to a passing pantograph in order to ensure safe and reliable train operations. A standard pantograph gauge includes 3 envelopes: - the pantograph "static" outline itself, - the added "raised & oscillated" pantograph profile, and - the further added "electrical clearance" envelope.	*6.3.2.3* – page *894*.
Pantograph Pan	Part of the head of a pantograph which carries the carbon collector strip. Its name derives from the previous use as a pan for grease lubricant when used with metal collector strips (this used to grease the contact wire for better wearing, but was eventually replaced with carbon strips which promote extremely good wear on the contact wire). Recent designs include a mechanism that causes the pantograph to lower (retract) if the carbon strip is worn below a certain level, thus preventing further damage to the contact wire and OHW system.	*6.3.1.1* – page *882*.
Pantograph Security	Mathematical justification that the pantograph head, by virtue of its overall dimensions, will not get hooked under the wire during operating conditions even when allowable tolerances for track condition, vehicle sway, wind speed, pantograph sway, cantilever and mast deflection, and erection tolerances may be adversely applying at the same time.	*6.3.2.2* – page *890*.
Pantograph Sway	Lateral displacement of the pantograph induced by roll and lateral shock loads.	*6.3.2.3* – page *894*.

Pantograph Uplift	The nominal upward force exerted by the pantograph on the overhead wire, usually between 100 and 130 N under static conditions.	*3.1.2.5 – Contact Uplift with Pantographs* – page *125*.
Pedestal	The top surface of a formed concrete foundation of mast or portal leg. This is usually the support surface for the plate connecting a mast or portal leg to the concrete foundation, and using hold down bolts protruding out of the concrete to hold the structure in place.	*3.3.0.5 – Footing* – page *405*.
Pennant	An out-of-running catenary or contact wire connecting in-running wires or connecting an in-running wire to a termination. Pennants may be alive or dead.	*3.5.0.5 – Main Reasons for Using Pennant Insulators* – page *496*.
Pennant Bay	The bay or bays that take a catenary & contact pennant wires from out-of-running to anchor.	*3.1.3.5 – Dropper Spacing* – page *166*.
Permit to work	A form issued as an assurance that the OHW has been correctly isolated & rail-connected for work to be carried out on or near the OHW. It is issued to the foreman carrying out the work and is held by him for the duration of the work.	
Pins	Typically, these are defined short lengths of 16mm or 19mm diameter stainless steel rod, used for connecting 2 parts together. E.g. 511/32 (16mm) and 120/5 (19mm). *16mm Pin* – typically used for pull-off arrangements. *19mm Pin* – normally used for in-line conductor tensions which are much higher than for pull-off arrangements.	*5.1.20.1 – Pin Connections* – page *749*.
Pipe	The strut member or jib of a cantilever.	*3.2.0.3 – Cantilever Pipe ("Jib")* – page *286*.
Planted Post (PP)	A mast that's planted into a hole bored into the ground, and backfilled with concrete. This is the most economical way of installing most masts in typical ground conditions.	*3.3.2.4* – page *416*
Platform	The area at a station designed for people to conveniently and safely alight from a train. The height of the platform can vary between standards – *Level Access* and *Easy Access*	
PO_Calc	A spreadsheet program written by Sydney's Railway Electrical Design Office, that determines all construction details necessary for staff to install various Mark-2 OHW pull-off arrangements.	*6.2.2.2* – page *879*.
Pocket	A cavity formed in the lining of a tunnel or such structure, to allow for the installation of OHW support & registration equipment. The pocket is normally required because of inadequate clearances to mount hardware on the lining surface. Although there is often adequate mechanical clearance to passing train pantographs, the pockets can be more for attaining suitable electrical clearances (150mm typically).	*6.4.1* – page *902*.
Polygon	A cross-span arrangement between masts which primarily supports the vertical loads of catenaries on multi-track construction. It can also register the pull-off radial loads of the contact wires and place the contacts at the required staggers.	*3.2.3* – page *342*.
Portal	- A frame support structure consisting of vertical masts (legs) supporting each end of a horizontal bridge which crosses the	*3.3.3* – page *418*.

	track. Often used in conjunction with one or more drop verticals installed from the portal bridge. - The entrance or exit of a tunnel.	
Post Type Insulator	An insulator with rigid mountings at each end.	*3.2.0.3 – Post Type Insulators* – page *249*.
PP	A type of mast. See "Plated Post".	
Preform Wrapon	A trade name for a wrap-around type of conductor termination. Several strands of wire wrap around the outside of a stranded catenary wire to lock onto this wire – the tighter the pulling tension, the stronger the grip on the catenary wire gets.	*3.1.9.4 – Preform Wrap-on* – page *220*.
Presag	An OHW design technique in tension regulated equipment which improves current collection at high train speeds by letting the contact wire sag in mid bay, usually by an amount equal to the Bay Length / 1,000. Presag = The static difference between the average contact wire height at the end droppers in a bay and the height at mid-bay (mid-span).	*3.1.2.5 – Contact Wire "Hog" & "Presag"* – page *124*.
Primary Insulation	The main insulation applied to anchor, support and register various OHW conductors, to ensure safe and reliable operation at 1500V, even under extreme weather (driving rain, etc.) and environmental conditions (pollution, etc.).	*2.9 – 1500V Insulation* – page *62*. *3.12.0.5 – Levels of Insulation* – page *614*.
Pulley System	The combination of 3 pulley wheels and its attachments as used with weight tension regulators.	*3.4.2* – page *449*.
Pull-Off / Push-Off	The registration towards or away from centreline of track in relation to the mast. These do not support any weight.	*3.2.4* – page *346*.
Pull-Off Arm (Steady Arm)	A length of steel flat plate or steel tube with suitable end fittings which is attached to the contact wire at one end and some form of insulated arrangement at the other, back to the mast for drop vertical. The pull-off arm is used to set the contact wire stagger, and in turn holds the consequent radial load (and wind load). The arm should wherever possible be in tension to assist better dynamic interaction with the train pantographs.	*3.2.0.3* – page *256*.
Pull-Off Bracket Height	In a cantilever arrangement, this is the height to the underside of the pull-off bracket (if used) on the mast, portal leg or drop vertical.	*3.2.1.4* – page *290*.
Push-Off Arm	A registration arm that's in compression (usually occurring on straight or near-straight track). This is an undesirable outcome, as arms should ideally be in tension (to help promote better pantograph interaction at speed).	*3.2.0.3* – page *256*.
Radial Load	Across-track horizontal load applied by conductors due to their deviation from straight by the registration arrangement.	*2.5.6 – Radial Load* – page *46*. *5.1.23.8 – Adverse Condition* – page *768*.
Rail	A steel section used to support the weight and lateral forces imposed by train wheels. Two rails separated 1,435mm are required to form a track. Various rail sizes exist (identified by their weight per metre, which is effectively the cross-section area), the most common being:	*6.2.1 – Track Terminology* – page *860*.

	153kg/m – is the older size. The rail is about 157mm tall. *160kg/m* – is a recent addition (1990s?). The rail is about 170mm tall.	
Rail Bond	A solid wire connection to one rail of a track. E.g. spark gaps are connected to track with a rail bond to the "traction rail".	*3.12 – (Bonding)* – page *598*.
Rail Connection	The connection of a cable to one rail of a track. This connection can be a "thermit" weld bonding the copper wires directly to the steel rail, or by special expanding bolted connection to the web of the rail.	*3.12.0.5 – Rail Connection* – page *613*.
Rail-Connected	The electrical state of OHW conductors that whereby the de-energized conductors are electrically connected to the track. This is done to help make it safe to then work on the OHW equipment (the OHW is then at the same electrical potential as the track below).	*2.5.2* – page *40*.
Rail-Earth Contactor (REC)	A special switch located inside a substation or sectioning hut, that's designed to remain open until a preset rail-to-earth voltage is exceeded, whence the switch closes to connect the negative rail (-1500V) to electrically substation earth.	*6.1.3 – Rail-Earth Contactor* – page *859*.
Rail Level (RL)	The level of the lower of the 2 rails of a track at any location. For OHW design work, the Design RL is required – measuring Existing RL shows how much the track is currently out of place (vertically). Not to be confused with Reduced Level (RL).	*6.2.1.8 – (Low) Rail Level* – page *868*.
Rake	The lean of a mast from vertical. A positive rake places the top of the mast further away from the track being serviced. The rake helps the mast look vertical when it is finally loaded by the cantilever and OHW conductors. Typically, a mast is installed with a rake of +17mm in 2,000mm vertical. The rake used to be measured by a purpose-designed "Rakeometer".	*3.3.0.5 – Mast Rake & Deflection* – page *404*.
Ramset Nail (RSN)	A marker installed in the mast, usually installed by a surveyor, to reference the *design* position of the track, in terms of (a) its horizontal offset (to near rail), (b) rail level (the lower of the 2 rails of the track) and (c) track superelevation. The nail is usually set 300mm above design rail level.	*6.2.2* – page *876*.
Rattler	A dropper that is not supporting any contact wire weight tends to rattle – a "rattler". This looseness is not only annoying to neighbours, it can lead to premature wear of the dropper components.	*3.1.3.5 – Adjustments* – page *176* .
RegDrop (program)	A computer program written by Sydney's Railway Electrical Design Office using the Pascal language, that determines OHW dropper lengths and positions for bays of regulated OHW. Runs on MS-Dos. (A more recent dropper program written in Visual Basic for Excel calculates droppers accurately in wire runs for all types of bays – normal, pennant, overlap, etc.)	*3.1.3.5 – Dropper Programs* – page *170*.
Registration	Lateral constraint of conductors to set a particular stagger.	*2.3.2* – page *30*.
Registration Arm	See Pull-Off Arm.	
Regulated Tension	An OHW system in which the catenary and contact tensions are regulated at nominally constant tension irrespective of temperature changes. This is achieved by rigidly anchoring	*2.5.3* – page *41*.

	the catenary and contact at one end and placing a system of weights or other tension regulator device at the other end. As the wires expand or contract due to changes in the temperature, the device "takes up" the changes in conductor length, thereby keeping the tension in each conductor constant. For economy, two fixed ends may be arranged back-to-back, forming a "fixed mid-point".	
Reverse Wind Load	A wind load in opposite direction to the contact radial load. See "Adverse Condition"	
Reduced Level or Relative Level (RL)	Surveying terms that define the level of an object relative to some other standard level. RLs are determined and provided by surveyors when they locate objects in 3-D. They are extremely useful, as they provide a convenient means of determining a relative clearance to some other object. E.g. a catenary under a bridge might have an RL of 52.125m and the underside of bridge might be 52.605m – the vertical clearance from catenary to bridge is thus 0.480m.	*5.1.31 – 3 Dimensions* – page *785*.
Road-Rail Equipment	Cranes, trucks, etc with flanged steel wheels and rubber tyres for operation on railways and on public roads.	*5.2.2.2* – page *796*.
Rollers (Catenary Rollers)	A catenary roller supports a regulated catenary wire, usually under an overline bridge with small vertical clearance to the bridge. It allows the wire to move longitudinally with temperature. Special upper & lower rollers trap the catenary and either support the catenary weight or prevent the catenary from rising (uplift). The rollers can be made from "Delrin" (plastic) or brass.	*3.2.5.4 – Catenary Rollers* – page *355*.
Running Wire	The process of erecting the OHW by placing the catenary wire into gin wheels, and then running the contact wire from intermediate wheels suspended from the catenary.	*5.2.3 – Installing OHW* – page *798*.
RVX-4	A purpose-built vehicle that routinely traversed the rail network to measure and identify exceedances of track and OHW infrastructure (relative to current track position). Output included video of pantograph/contact wire interface whilst travelling, and paper output of contact stagger & heights for locating exceedances (with track kilometrage).	*5.4.2 – RVX-4* – page *818*.
Saddle Clamp (Catenary Saddle Clamp)	A 2-piece gunmetal cast fitting which clamps around the catenary wire with a single bolt. It can be used to: (a) support and locate a short or restricted dropper on the catenary wire. The clamp has a cam action that can provide some fine adjustment when rotated, to prevent droppers from rattling. (b) terminate a span wire around a catenary wire and so protect the catenary wire from damage.	*3.2.0.3 – Catenary Saddle Clamp* – page *262*.
Sag	Average height of conductor at adjacent supports minus its height at the mid-point in a bay.	*3.1.1.5 – Catenary Sag* – page *104*.
Sagging	The process of correctly setting the tension in a catenary by measuring the sags in representative bays.	*5.2.3* – page *798*.
Secondary Insulation	Insulation in addition to the main Primary insulation, which is intended to help reduce the likelihood of stray currents and improve the earthing situation.	*3.12.0.5 – Levels of Insulation* – page *614*.
Section (Electrical Section)	A unique electrical zone which can be energized or isolated by switching or the installation/removal of feeder jumpers.	*5.3.2* – page *811*.

Section Insulator (SI)	A device for conveniently dividing the OHW into electrical sections while maintaining mechanical continuity and a continuous path for pantographs. Section insulators take up much less space than providing a sectionable overlap, which is the normal alternative.	*3.6* – page *508*.
Sectioning	The dividing of an electrical distribution system or network into electrical sections.	*5.3.2* – page *811*.
Sectioning Hut (S/H)	A track-side building containing dc circuit breakers (DCCBs) for sectioning the OHW (which provides protection and isolations for subsequent maintenance work), and electrically paralleling the OHW (to improve voltage regulation at the train).	*1.7.2* – page *15*. *2.3.8* – page *34*. *6.1* – page *854*.
Separator	In side-strain insulators – a steel link (typically 150mm long) or "Insulator Link Bar" is often inserted between the two insulators. This improves the lightning flashover performance of the insulator pair.	*3.2.0.3 – Insulator Link Bar* – page *254*.
Set Screw	A bolt with its shaft length fully threaded. This can allow the fastener to tighten 2 or more thin objects together using a nut, or a thin object to a threaded insert, without the risk of running out of thread. E.g. needed to clamp a flange to the resin post type insulator (fitting 452/10).	*5.1.20.1 – Set Screws* – page *748*.
SI	See "Section Insulator".	
Side Strain	The cross-track tensile loading imposed by the contact radial load and/or the cross-span tension (between opposing masts). "Side strain insulators" are often located next to the mast to take the contact radial and wind load (they are NOT designed to take the contact tension load).	*3.2.0.3 – Insulator Link Bar* – page *254*.
Siding	A track used for the storage of vehicles or for the loading or unloading of freight.	*6.2.1.5* – page *864*.
Signal Rail	The rail of a track so designated by Signals discipline. See also "Traction Rail".	*6.5.4 – Bonding to "Traction Rail"* – page *922*.
Skirt	The corrugated underside surface of the insulation on a disc or post type insulator. The corrugated surface is intended to extend the creepage path (from live to dead side of insulator) so as to reduce any leakage currents across the insulation. Where possible, the corrugation surface should be installed in a way that offers shielding from rain, to prevent a continuous water stream across the insulator.	*2.9* – page *62*.
Sleepers	The immediate support for the 2 rails of a track. They provide a suitable interface to the ballast underneath, and ensure the rails of a track are maintained at the required track gauge (1,435mm). They also offer some cushion effect to reduce the transfer of rail-generated vibration. In some circumstances the rails can be directly fixed to the structure below without sleepers. *Timber Sleepers* – There are generally made of hardwood for resilience. *Concrete Sleepers* – Introduced in the 1980s, they are thicker than timber sleepers, and are much heavier which means they can more effectively anchor the track in position.	*6.2.1.4* – page *863*.
Sliding Knuckle	A rigid bar about 1.5 m long fixed closely above the in-running contact wire forming a slot for a second contact wire	*3.1.5.4 – Sliding Knuckle* – page *190*.

	to pass through. Normally used at turnouts with regulated contact wire, which moves longitudinally with temperature.	
Soffit	The underside of the deck of a bridge; the inside roof of a tunnel.	
Span Length	See "Bay Length".	
Span Wire	A wire of typically 90mm² (37/1.75mm) hard-drawn stranded copper, installed from a mast for the purpose of registering radial and wind loads on conductors. *One-Third Span* – The span wire terminates on a mast or portal leg and registers OHW conductors for the closest track. *Two-Third Span* – The span wire crosses the closest track over to register the OHW for the 2nd track in a normal 2 track situation. *Full Span* – The span wire crosses all tracks from one mast to the opposite mast. It usually registers all sets of OHW along the way.	*3.2.0.3 – Cross-Span Wire* – page *260*.
Spark Gap	An insulating device installed between an OHW structure and the traction return rail, which short circuits at a predetermined abnormally high voltage (about 600V) to electrically connect the structure to the rail. This is an electrical protection mechanism and is intended to provide a low resistance path to trip the dccb protection in case the structure livens up, e.g. due to insulation failure or collision. In its normal *Open* state, it is used to isolate the equipment being protected by the spark gap from the voltage on the rails of a track and prevent stray current (and associated corrosion). In its *Closed* state, it is used to complete the electrical circuit and trip the adjacent d.c. circuit breakers under heavy current fault conditions. It can only be reset to the open state by replacement with a new spark gap module.	*3.12.0.5 – The Simple Spark Gap* – page *607*.
Splice	The term used when connecting wires together so that they can take full tension. Various splices are available for both the contact and catenary wires. *Contact full-splice* – Used to connect 2 contact wires together, allowing pantographs to pass through. *Contact half-splice* – Used to terminate a contact wire, e.g. 2 half-splices connect the contact wire onto a section insulator (one splice at each end of the SI).	*3.1.7 – Contact Splices* – page *205*. *3.1.9 – Catenary Splices* – page *219*.
Stagger (Contact Stagger)	Stagger is the horizontal distance the contact wire is pulled off from the superelevated centreline of the track at a registration point. Stagger is applied to the contact wire (and the catenary wire is located vertically above this position). On *straight track* the contact wire is staggered to alternate sides of the track centreline at each structure (it zig-zags). This allows for more even wear of the carbon strips on each pantograph as the contact wire sweeps across the pantograph. On *curved track* the wire is pulled towards the outside of the curve, which helps achieve larger bay lengths while also promoting more even pantograph carbon strip wear.	*3.1.2.5 – Contact Stagger* – page *129*.

	Typical standard stagger values are 250mm or 300mm. See also "cantilever coding system" for definition of positive and negative staggers for coding purposes.	
Static Position of Contact Wire	The position of the contact wire without uplift and without wind.	
Stay	See "guy".	
Steady Arm	See " registration arm".	
Steady Span	A span wire used to control the lateral position of a contact wire (with appropriate pull-off arm), or a catenary wire.	*3.2.3.4* – page *342*.
Step Potential	The term given to the voltage difference (typically on the ground) between the feet of a person. Any significant voltage difference can lead to current flowing through the legs and body which, depending on its duration, can possibly have lethal consequences. Situations involving significant step potentials need to be checked out and addressed.	*3.7.0.5 – Equipotential Operator's Platform* – page *551*.
Stiction	The friction which tends to prevent stationary surfaces from being set in motion. This non-ideal behaviour applies most notably to the tension regulator pulleys – the friction in their roller bearings needs to be overcome (by a certain amount of tension imbalance) before the wheels can begin to rotate and the weights move to a new vertical position.	*3.4.2.5 – Friction* – page *464*.
Stop Beam	This device is sometimes installed on overline bridges to prevent the unrestrained catenary wire from lifting up and touching the bridge because of tight clearances. It typically consists of a horizontal beam of insulating material with end brackets to attach it to the bridge. It is desirable to design the OHW under a bridge such that they are not required.	*3.2.0.3 – Insulated Stop Beam* – page *265*.
Stranded Wire	A conductor which is composed of a number of smaller strands, e.g. the catenary wire. This makes the wire easier to bend and therefore easier to install. For all of Sydney's catenary wires, the outer-most layer of strands is standardised as "right hand lay" (i.e. it spirals in a clockwise direction as is heads away).	*2.5.1* – page *39*.
Stranding	The process of severed wire strands unravelling, usually beginning with the outer strands. Any stranding of the catenary wire requires immediate repair, for a number of reasons (including uncontrolled risk of a long strand flashing over to nearby objects, reduced current carrying capacity / increased risk of annealing under tension, etc.).	*3.1.1.5 – Wire Stranding* – page *114*.
Stringing	The process of anchoring a conductor, then running it from support to support whilst under tension, then anchoring at the other end of the wire run. Applies to catenary and also to contact wires.	*5.2.3* – page *798*.
Stringline	Straight lines, as would occur with a taut string. Often used to measure: shortest distance around an object, or distance from an object to this straight line. See "versine".	*Figure 605* – page *770*.
Structure (Support Structure)	A principal support such as a mast or portal. The term covers any type of support used to hold the overhead wiring support & registration equipment.	*3.3* – page *388*.
Structure Location Number	All OHW support structures and other significant infrastructure are required to be uniquely identifiable by a Structure Location Number. *Example:* SL123+456. It is the	*5.3.3* – page *811*.

	number that appears as black text on a reflective yellow background, often glued or riveted to the structure.	
Structure Offset	The dimension from centreline of mast or portal leg to centreline of track. Typically, structures are located 3.2m from closest face of structure to the track in order to give plenty of passing clearance to trains.	*3.3.0.5 – Structure Leg Placement* – page *403*.
Structure Setout	The laying out of proposed OHW structures in the field.	*3.3.0.5 – Structure Setout* – page *395*.
Structure Spacing Chart	A table of numbers that, among other things, shows how far OHW support structures can be spaced as a function of track curvature of varying radii, i.e. bay length versus track radius. The tighter the track radius the smaller the maximum bay length. It also gives various catenary and contact loadings, etc. for the combination of bay length and radius. There are several tables available, each applying to a specific OHW system.	*3.2.0.2* – page *245*.
Substation (S/S)	A track-side building where electricity is transformed from high voltage ac (132kV, 66kV, 33kV), and rectified to 1500V dc. A typical railway substation contains high-voltage ac switchgear, main transformers, rectifiers, a feeder circuit-breaker for each track in each direction, a control battery (120V), protection relays, a supervisory control remote station, and auxiliaries. Redundancy of equipment is a key requirement inside a substation to increase reliability.	*1.7.2* – page *15*. *2.3.8* – page *34*. *6.1* – page *854*.
Superelevation	One rail of a track is higher than the other to counter centrifugal force on curves, to give passengers a more comfortable ride. Superelevation is measured as the vertical difference in levels of the 2 rails of a track.	*6.2.1.11* – page *871*.
Superelevation Effect	Horizontal displacement of the pantograph centreline from the vertical track centreline at contact wire level due to track superelevation. This is important to know when designing support & registration arrangements to deliver the correct contact wire stagger.	*3.1.2.5 – Contact Stagger* – page *129*.
Supervisory Control & Data Acquisition (SCADA)	An extensive electronic system that senses the status of various electrical items in the Electric Traction Network, and allows the control of various items of electrical infrastructure from the Electrical Operating Centre. Importantly for OHW, this includes the control of DCCBs in S/Ss and S/Hs.	
Supplementary Insulation	Refers to the Secondary or Tertiary insulation (which is in addition to the main Primary 1500V insulation).	*3.12.0.5 – Levels of Insulation* – page *614*.
Support & Registration (S&R)	The equipment used to support the OHW conductors and/or register their radial and wind loads. This S&R equipment is supported from a mast, portal or drop vertical suspended from a portal bridge, and this equipment in turn supports the catenary and contact wires, placing them at their correct spatial position (especially contact height and stagger).	*3.2* – page *245*.
Surge Arrester (Surge Diverter)	This device is intended for the protection of electrical equipment against the effects of lightning surges travelling on OHW conductors. If properly designed and installed, this device attempts to:	*3.9* – page *583*.

	(a) *Clamp the voltage* across the item of electrical equipment being protected, to prevent over-voltage damage (e.g. cable XLPE insulation), and (b) *Divert the lightning surge* to ground, so as to reduce the likelihood of the surge further damaging electrical equipment elsewhere. Surge Arresters are typically installed at the OHW end of a 1500V cable which feeds the OHW, to protect the vulnerable cable insulation.	
Survey	Specific distance information obtained by a Surveyor that defines various points in space, including the track (existing and design positions), OHW conductor heights and staggers, heights to underside of overline bridges, etc. This information is vital to the effective design of OHW. Information is usually provided in 3-D in terms of "Eastings", "Northings" and "RLs", and based on the MGA (current) or ISG (older) coordinate systems.	*5.1.31 – The Role of Survey* – page *785*.
Suspension Angle	A type of support for the OHW on a bridge. See also "L-iron" or "T-iron".	*3.2.5.4 – Suspension Angle* – page *354*.
Sustarin-C	An acetal co-polymer, used in OHW for providing secondary or tertiary insulation, etc.	*5.1.18.2 – Acetal Resin* – page *745*.
Switch	A device that can connect or disconnect electrical supply to the OHW system. When in the "Open" position, the switch needs to be able to withstand applied voltages across its terminals without causing current to flow. When in the "Closed" position it must be able to carry heavy current (typically 3,000amps) over a period of time. *Feeder Switch* – a switch for feeding or sectioning electrical circuits. *Isolating Switch* – a switch provided for isolating and/or earthing electrical apparatus and circuits. *Isolating & Rail-Connecting Switch* – a 3-position switch configured to connect 2 OHW electrical sections together in one position, isolating the 2 sections at some intermediate switch position and connecting one of the sections to rail in the third position.	*3.7* – page *535*.
Swivel Clamp (Contact Swivel Clamp)	A clamp that connects to the end of a pull off arm and attaches to the upper wedge of the contact wire. It is made to take the high radial loads imposed by the contact wire, and is designed to allow a certain amount of swivelling to take place mostly to avoid fatigue, e.g. contact wire uplift with passing pantographs, and contact wire longitudinal movement with temperature in a regulated OHW system.	*3.2.0.3 – Contact Swivel Clamp* – page *259*.
System Depth	The vertical distance between centre of catenary and underside of new contact wire, normally taken at the catenary support structure. The current standard system depth is 1.5m for regulated support & registration cantilever equipment.	*3.2.0.5 – System Depth* – page *278*.
Tail	A short piece of OHW catenary or contact wire, or bared cable at the termination end. This is usually for the purpose of making an effective electrical connection to another piece of equipment. A catenary tail is normally under no mechanical tension, and this allows a heavy current connection to be made to this tail	*3.8.0.5 – Catenary Feeding Tail* – page *575*.

	without fear of a high resistance joint overheating the wire, annealing it and stretching to failure if it were under normal tension. Making a heavy current connection this way is an important rule for Sydney's OHW system.	
Tangent Track	The straight portion of track between curves or transitions. This is normally associated with zero track superelevation.	*6.2.1.9* – page *868*.
Tangling	An event where a pantograph strikes any part of the OHW which it is not designed to run on, and usually causes damage to both the pantograph and the OHW. The damaged OHW and pantograph typically "tangle" together in this unfortunate situation.	*2.4* – page *37*.
Temperature / Tension Chart	An important graph showing the relationship of catenary tension as a function of its temperature and virtual span, and is applicable only to OHW that is fixed-anchored. (*Note:* this applies to regulated OHW during construction before the weight tensioners are connected.) Different charts are available for the various OHW systems. *Unloaded Tension* – This chart shows the behaviour of catenary tension with temperature when only the catenary has been run, i.e. in its unloaded state (no contact, droppers or in-span feeders installed). It's a clever chart that predicts what the catenary tension should be in this state at any temperature, such that when it is later loaded with the contact weight etc., it will be at its final design (loaded) tension with no further tension adjustments needed. The below "Loaded" chart then applies. *Loaded Tension* – This chart shows the behaviour of catenary tension when the catenary is finally loaded with the weight of the contact wire, droppers and in-span feeders.	*3.1.1.5 – Tension Changes* – page *105*.
Tension Length	*Fixed-Anchored OHW* – The length of OHW conductors from anchor to anchor. This distance can be relatively short (100m) but can also extend up to a few kilometres. *Regulated OHW* – The distance from a Fixed anchor or fixed mid-point anchor, to a tension regulator anchor point. Typically, this distance seldom exceeds 1,000m (due to need to cater for the amount of expansion and contraction of copper wire with temperature extremes). There are 2 tension lengths for wire runs that include a fixed mid-point anchor, and these wire runs can thus be up to about 2,000m or a bit more. On curved track, the tension length needs to be reduced due to the tightness of the curve, which can cause excessive tension deviation from design towards the fixed anchor or fixed mid-point anchor location.	*3.1.0.4 – Tension Lengths* – page *76*.
Tension Regulated System	An overhead wiring system in which conductor tensions are kept nominally constant by a device (a tension regulator) that accommodates the expansion and contraction of the conductors due to temperature.	*2.5.3* – page *41*.
Tension Regulator	An assembly of weights and pulleys, or gas device, or spring device, which maintains a relatively constant tension in a tension length of OHW conductors. On the OHW Layout, this device is shown as a "Moving" anchor with symbol "M" (inside a circle).	*3.4* – page *432*.

Tensioning	The application of tension to the OHW conductors. There are several methods available to achieve this tensioning.	*3.4* – page *432*.
Termination	The point where a wire length finishes and needs to be terminated with appropriate fittings for connection to another part.	*3.1.6 – Contact Termination Clamps* – page *199*. *3.1.7 – Contact Splices* – page *205*. *3.1.8 – Catenary Termination Clamps* – page *213*. *3.1.9 – Catenary Splices* – page *219*.
Tertiary Insulation	Insulation that is in addition to the main Primary insulation and added Secondary insulation. The 3 levels of insulation significantly decrease the likelihood of stray d.c. currents flowing from the live +1500V OHW. This scheme can bring about advantages especially in sensitive areas where leakage currents need to be avoided (both from the live 1500V OHW, and from rail volts via bonding wire circuit when the spark gap is shorted).	*3.12.0.5 – Levels of Insulation* – page *614*.
Test Point	This is typically an electrical terminal that's provided in a convenient location for testing for either the electrical continuity or isolation (whichever is desirable) of steel reinforcing within concrete beams or slabs, with respect to an adjacent structural section or service. In this situation typically all steel reinforcing in a concrete structure or part of structure is connected together for testing. Once the concrete has set, it is sometimes almost impossible to check for isolation or continuity in some other way.	*3.12.0.4 – Configuration* – page *601*. *6.4.6.3 – OHW Structure Bonding* – page *914*.
Thimble	A fitting used at some wire terminations to minimise stress and fatigue on the wire and on the termination equipment. E.g. Fittings T11/7 and T11/17. Often these thimbles are made from a softer metal than the terminated wire, e.g. soft copper used when terminating hard-drawn bare copper (see fitting T11/7). *Open Thimble* – a loop to wrap wires around with the two ends spread apart, allowing insertion over a terminating pin. This type is normally shaped like a teardrop. *Closed Thimble* – the loop with its two ends close together. Often this takes the shape of a ring.	*3.2.0.3 – Thimble* – page *262*.
Tie-Rod Bracket Height	In a cantilever arrangement, this is the height to the underside of the top bracket on the mast, portal leg or drop vertical.	*3.2.1.4* – page *290*.
Tirfor	A lever-operated winch, suitable for pulling items including conductors under tension. (Trademark of the Tractel company.)	
Tongue & Clevis	Typically applies to the joining of insulators or other hardware, where a metal plate with hole (the tongue) on one component is inserted between a pair of plates with same hole size (the clevis) on the mating component, and joined together with a pin (typically 16mm or 19mm diameter stainless steel).	*2.9.1* – page *65*.

Touch Potential	The term given to the voltage difference typically between the hands of the two outstretched arms of a person. Any significant voltage difference can lead to current flowing through the heart which, depending on its duration, can possibly have lethal consequences. Situations involving significant touch potentials need to be checked out and addressed.	*3.7.0.5 – Equipotential Operator's Platform* – page *551*.
TP	Tangent Point on a length of track where the tangent on the curved track meets another piece of track.	*6.2.1.9* – page *868*.
Traction Rail	The rail or rails of a track deemed by Signal staff to take traction return currents.	*3.7.0.4 – Traction Rail* – page *543*. *6.5.4 – Bonding to "Traction Rail"* – page *922*.
Track Bond	An electrical connection to nearby signal impedance device between adjacent lengths of rail across an insulated rail joint (IRJ). This ensures the rail is continuous to dc for traction currents, but can block ac signalling currents as required by some signalling circuits (for train detection).	*6.5.4 – Bonding to "Traction Rail"* – page *922*.
Track Centres	The distance between centrelines of adjacent tracks. The distance between main lines (Up and Down tracks) used to be 3.66m in the old days, but changed many years ago to be 4.0m. The distance has to ensure passing train consists won't clash, and each track needs to be maintained within specified tolerances to assure this.	*6.2.1.11* – page *871*.
Track Gauge	The distance between the inside verticals of the rails of a track measured 15mm below the running surface. In NSW the track gauge is Stevenson's standard track gauge – 1,435mm.	*6.2.1* – page *860*.
Track Gradient	The slope of the track longitudinally. A "Curve & Track Gradient" book is available that shows the various track grades throughout NSW (if it is still updated).	*6.2.1.10* – page *870*.
Track Superelevation (Super)	The vertical difference in heights between the 2 rails of a particular track. Superelevation is the correct term. See CCalc documentation for the sign convention used for track super when designing and installing Mark-2 cantilevers.	*6.2.1.11* – page *871*.
Track Tolerance	The 3 tolerances used for maintaining track in its correct position. Track tolerances are extremely important because the track interfaces with many systems, including the OHW system, where it needs to be within its limits of the all-important contact wire position for reliable train operations. *Vertical* – allowable variation in Rail Level from its design position. Typically +50, -150mm *Lateral* – allowable variation in the track alignment from the design position. Typically ±50mm. *Superelevation* – allowable variation between height of each rail from its design value. Typically ±25mm. *Note:* The reference nail installed in OHW masts and portal legs throughout the electrified network has helped enormously to tie the design track position down, as it regularly (every 50m or so) shows the above 3 elements that define the design position of the tracks, particularly the horizontal offset from nail to track.	*6.2.2.1* – page *877*.

Tractel	A construction tool, similar to a chain block and used for pulling conductors under tension. See also "Chain Block", "Come-Along" and "Tirfor". Tractel is the company that makes this device (as well as the Tirfor).	*Figure 626* – page *800*.
Transition, Transition Spiral	See "curve – transition curve".	*6.2.1.9 – Horizontal Alignment* – page *868*.
TRS	This is where a transition spiral joins curved track. (Note that straight track is curved track with infinite radius.)	*6.2.1.9 – Horizontal Alignment* – page *868*.
Tunnel Cantilever	A cantilever specifically designed for supporting & registering the OHW conductors inside the often restricted space of a tunnel or low bridge, etc. Tunnel cantilevers for regulated OHW have the added design burden of allowing for catenary and contact longitudinal wire movement with temperature.	*3.2.6.4 – Regulated OHW Arrangements* – page *374*.
Turnout	The assembly of rails, switches and crossings where 1 track branches into 2.	*6.2.1.5* – page *864*.
Twisted Sleeve (or McPherson)	A simple piece of equipment used to terminate a 37/1.75mm HDBC span wire (90mm²), usually onto a thimble. The twisted sleeve is a copper tube placed over both a span wire and its return wire, then twisted using a special device to lock the two wires together. They are no longer used in new construction, as there are superior clamps available.	*3.2.0.3 – Twisted Sleeve* – page *261*. *Figure 184* – page *260*.
Underline Bridge (ULB)	Any passageway under the tracks.	*6.4.4* – page *905*.
Up Track	A track reference, defining a track where most train travel is intended to head *towards* Sydney. (See "Down Track" for the opposite direction)	*6.2.1.1 – Down & Up Tracks* – page *860*. *2.5.13* – page *54*.
Uplift	*Dynamic* – The amount and distribution of lift on the contact wire/s due to pantographs passing at speed. *Static* – The amount and distribution of lift on the contact wire/s due to pantographs parked under the OHW.	*3.1.2.2* – page *117*.
Versine	On curved track of constant radius, this is the horizontal offset of the track at mid-bay relative to a straight-line chord strung between track centres at both ends of the bay.	*3.1.2.5 – Mid-Bay Offset* – page *134*.
Virtual Span (VS)	Virtual Span is a mathematically-derived representative span length that applies to one or more bays in a tension length. If a catenary is supported and locked from longitudinal movement, then that location is the start or end of a particular virtual span zone. A long tension length can have several virtual spans. The tension behaviour of the conductor is dependent on its virtual span, and that's why it's so important to know the exact VS in the area of interest. Virtual span does not normally need to be considered in regulated tension systems when the tension regulators are installed and working. So, VS is input into the Temperature/Tension equation to determine the change of tension with temperature.	*3.1.0.5 – Virtual Span* – page *95*. *3.1.1.5 – Tension Changes* – page *105*.
Warning Barrier (or Portal)	A portal placed across the road on each side of the tracks at some level crossings on some railways to warn road traffic of the danger of the OHW, and act as a load gauge for road	*6.4.5 – Warning Barriers (or Portals)* – page *908*.

	traffic. Warning barriers (portals) are also used each side of low underline bridges.	
Wave Propagation Velocity	A critical velocity for an OHW system, whereby a pantograph on fast electric trains travelling above this speed will cause a wave to be generated in the contact wire in front of the train, which the train pantographs then have to pass through. The velocity of a travelling wave generated by an uplifted pantograph on contact wires. Among other things, it is a function of the combined contact tension and mass. (Refer EN 50119:2009)	*3.1.2.5 – Contact Wire Dynamics* – page *128*.
Way and Works Cantilever	This is effectively half a portal structure. A rigid steel leg, usually with stiffening knee-brace, which extends a portal bridge over an outer track. A "Nose" (drop vertical) is often installed at the remote end of the cantilever bridge, i.e. W&W Cantilever & Nose.	*3.3.3.4 – Cantilever & Nose Structure* – page *427*.
Web	The thin connecting piece between two flanges of a steel I-beam.	*3.3.0.5 – Universal Column (UC)* – page *395*.
Weight (Tension Regulator Weight)	A cast iron disc of pre-determined weight (usually 25kg) which is built up with other identical weights into weight stacks, installed in a tension regulator, for applying the required tension in the catenary and/or contact wires in regulated OHW.	*3.4.2.3 – Weight Stack* – page *450*.
Weight Guide Rod	The vertical rod which acts as a steady to the weight stack of a tension regulator. Helps to restrain weight movement especially under windy conditions.	*3.4.2.3 – Guide Rod Assembly* – page *451*.
WeightSet (program)	A spreadsheet program written by Sydney's Railway Electrical Design Office, that helps set up weight tension regulators. It ensures that the weights have the necessary freedom to move up and down with extremes of temperature. There are benefits to using this program in design, construction and ongoing maintenance aspects. Its strength is in the chart it produces that shows graphically the weight position under the extreme temperatures, and any impediments to movement. The program is mandatory for all new works, with the results passed onto the maintenance district for future checks. Runs on MS Excel.	*3.4.2.4 – The "WeightSet" Program* – page *457*.
WHVI (Working High Voltage Instruction)	An instruction, issued in accordance with the High Voltage Instructions, detailing the electrical isolation procedures and the work to be carried out on or near a transmission line or cable.	
Widened Knee-Brace (WKB)	A knee-brace with two angle struts that have been designed with increased separation to allow cantilever pipes supporting the OHW with large amounts of catenary and contact wire along-track movement. The additional space is virtually standard these days, making the term WKB less used.	*3.3.3.4 – Knee-Braces* – page *420*.
Wire	Bare conductor (i.e. not covered with insulation, otherwise it would be a "Cable").	*2.5.1* – page *39*.
Wire Down	A general term, usually used by operations to describe a situation where the OHW is damaged in some way and is unfit for running trains.	
Wire Run	One continuous length of OHW between anchors.	*2.3.1* – page *27*.

With Back To	The term used to define a person's orientation when viewing OHW infrastructure, such as a cross-section view of a portal with OHW equipment. This orientation is normally specified on the drawing to aid understanding. *With Back to Sydney* – This is the standard view when designing cross-sections, etc. Facing away from Sydney's Central Station (the main reference in NSW railway work), this has the Down track on the left and Up track on the right. *With Back to Country* – The opposite view to the above. An optional view if required for clarity. This has the Up side on the left and the Down side on the right.	*2.5.14* – page *54*.
Wrap-on	A type of wire termination that has individual helical spiral wire strands wrapped around the outside of the catenary wire. The strands must be in the same direction, i.e. right hand lay. The device needs to also be type tested and approved for use only on specific catenary sizes.	*3.1.9.4 – Preform Wrap-on* – page *220*.
XLPE Insulation	Cross-Linked Polyethylene (plastic) insulation. A special type of plastic that has extremely good insulating properties for use as the main dielectric in cables used in the HV ac and 1500V dc system. As with all cables the minimum bending radius must not be exceeded during construction. The main down side to this cable is that it must be sealed from water ingress, which can otherwise cause carbon "tree" paths throughout the insulation, eventually leading to flashover and failure. Joints are important to get right.	*2.5.1 – Cable* – page *39*.
Yoke	See Equalizer Bar.	

10 Appendices

10.1 APPENDIX "A" – OHW DESIGN DRAWING SAMPLES

The following pages show examples of typical OHW Design drawings that document how the OHW is (or was) to be constructed, and kept as a record for subsequent operational and maintenance activities, and used for any later changes.

- Electrical Sectioning Diagram
- Tension Length Diagram
- OHW Layout
- OHW Profile
- OHW Cross-Section
- OHW Bridge Arrangement
- Switching / Arrangement

Note that these drawings are samples only and are not necessarily up to date.

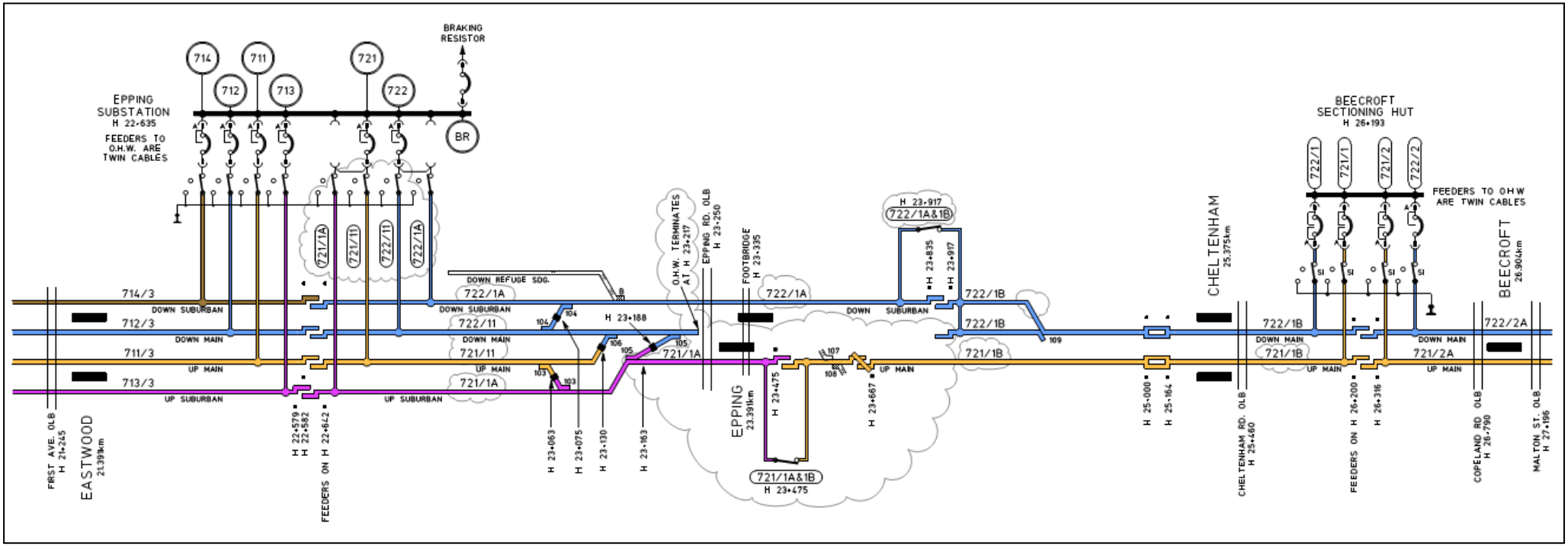


Figure 721 - Part-Copy of Typical Electrical Sectioning Diagram (Epping Staging Works, c. 2008)

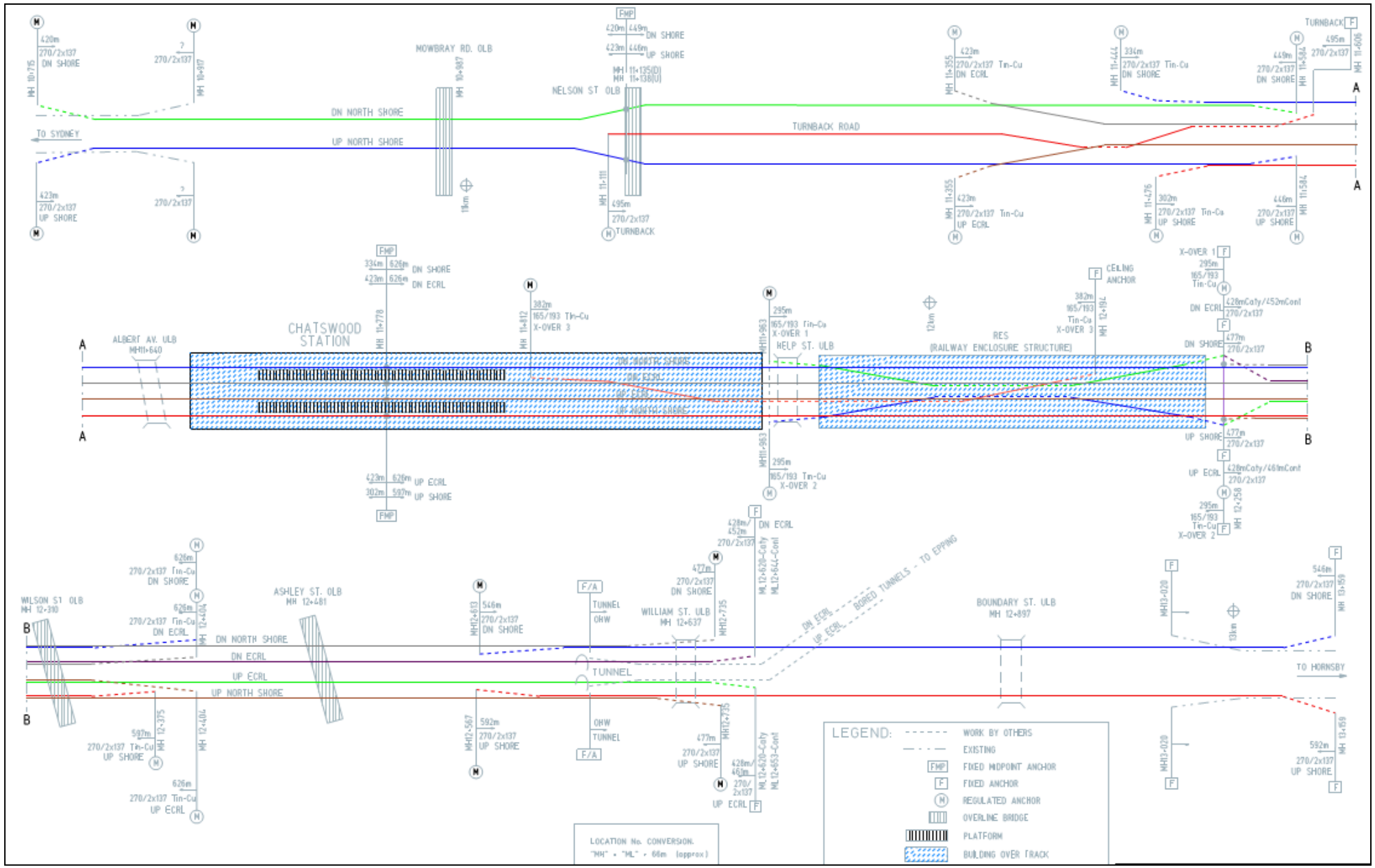


Figure 722 - Part-Copy of Typical Tension Length Diagram (Chatswood Proposal, c. 2008)

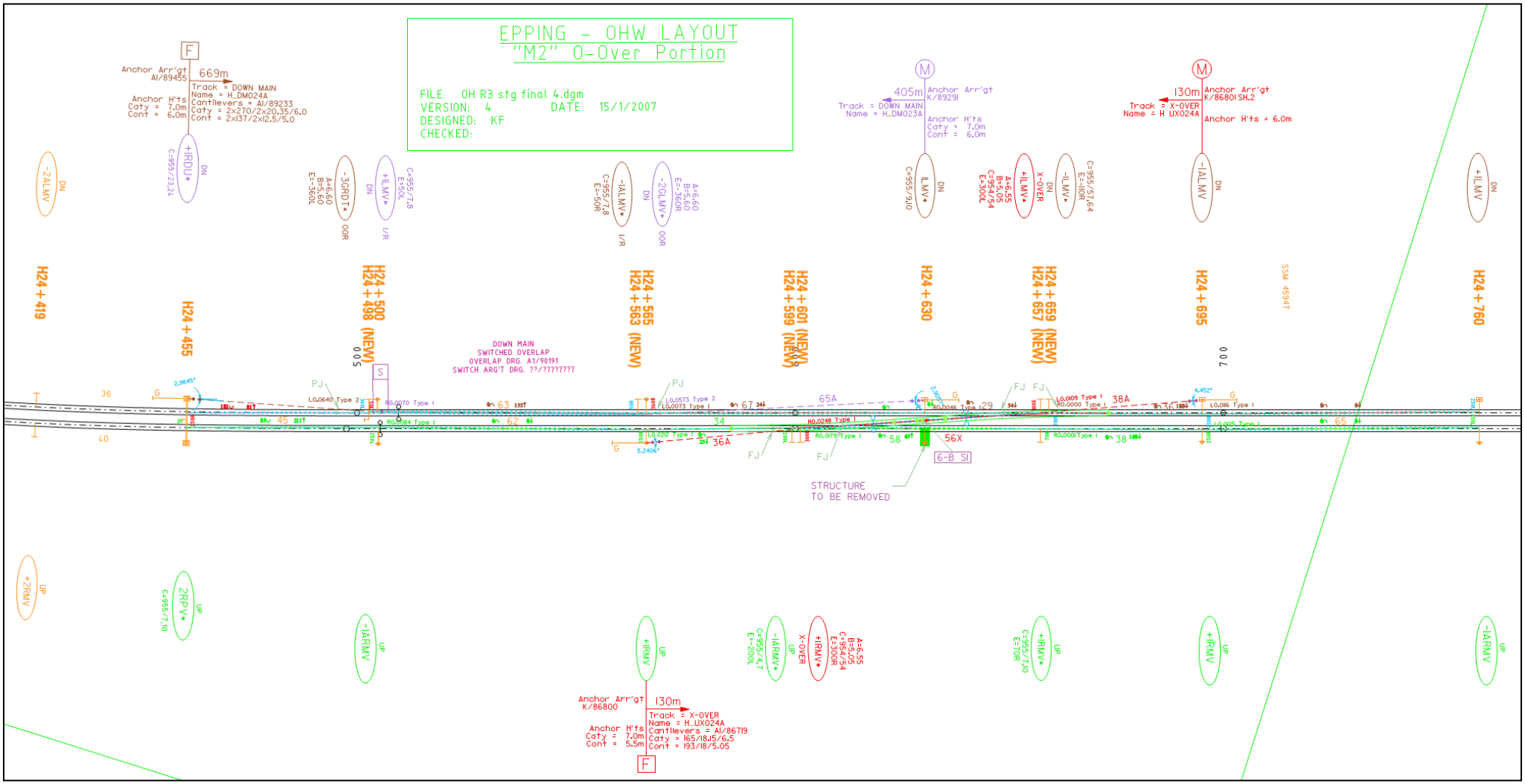


Figure 723 - Part-Copy of Typical OHW Layout (Epping)

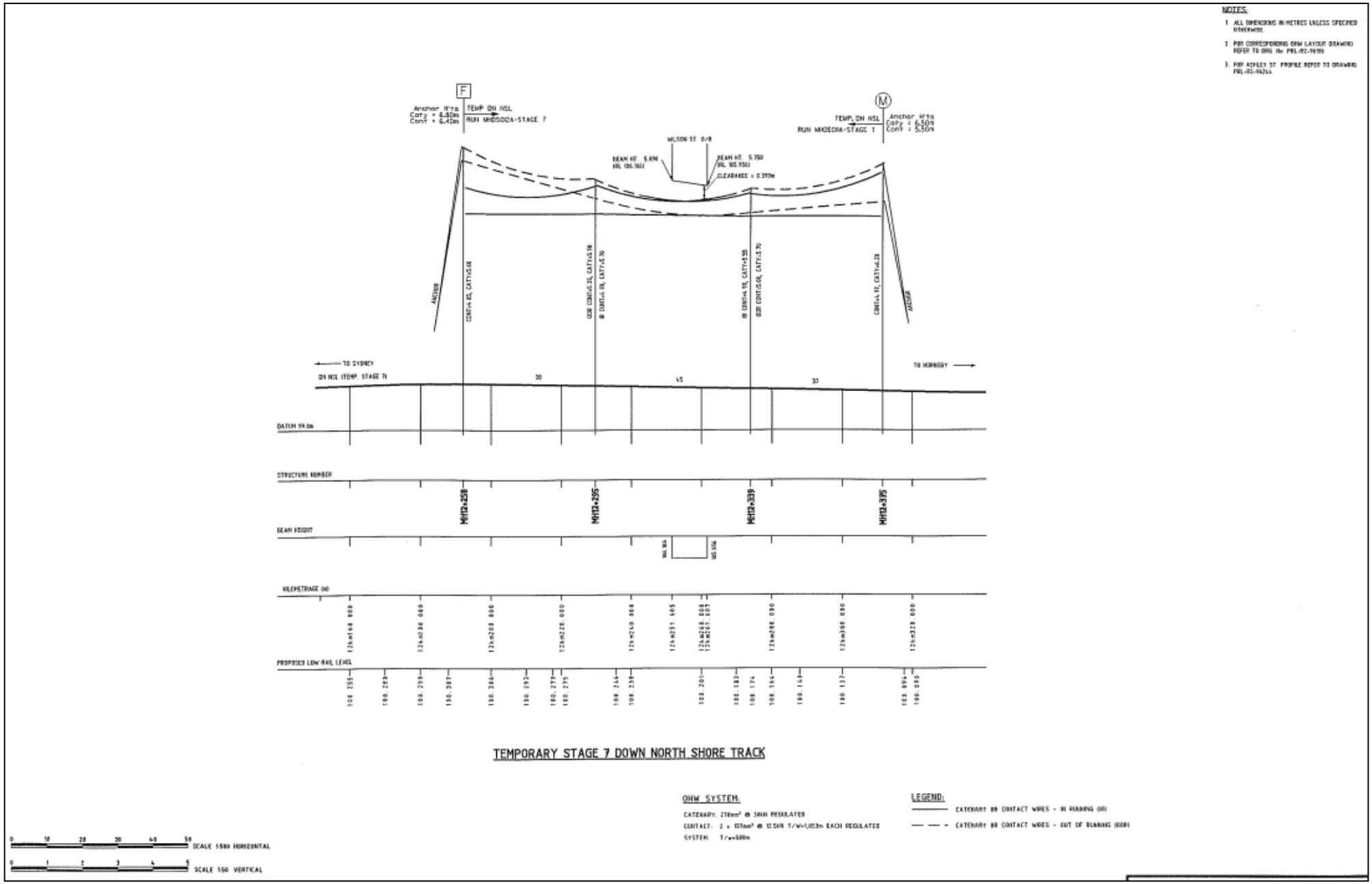


Figure 724 - Part-Copy of Typical OHW Profile (Chatswood Staging Works, c. 2008)

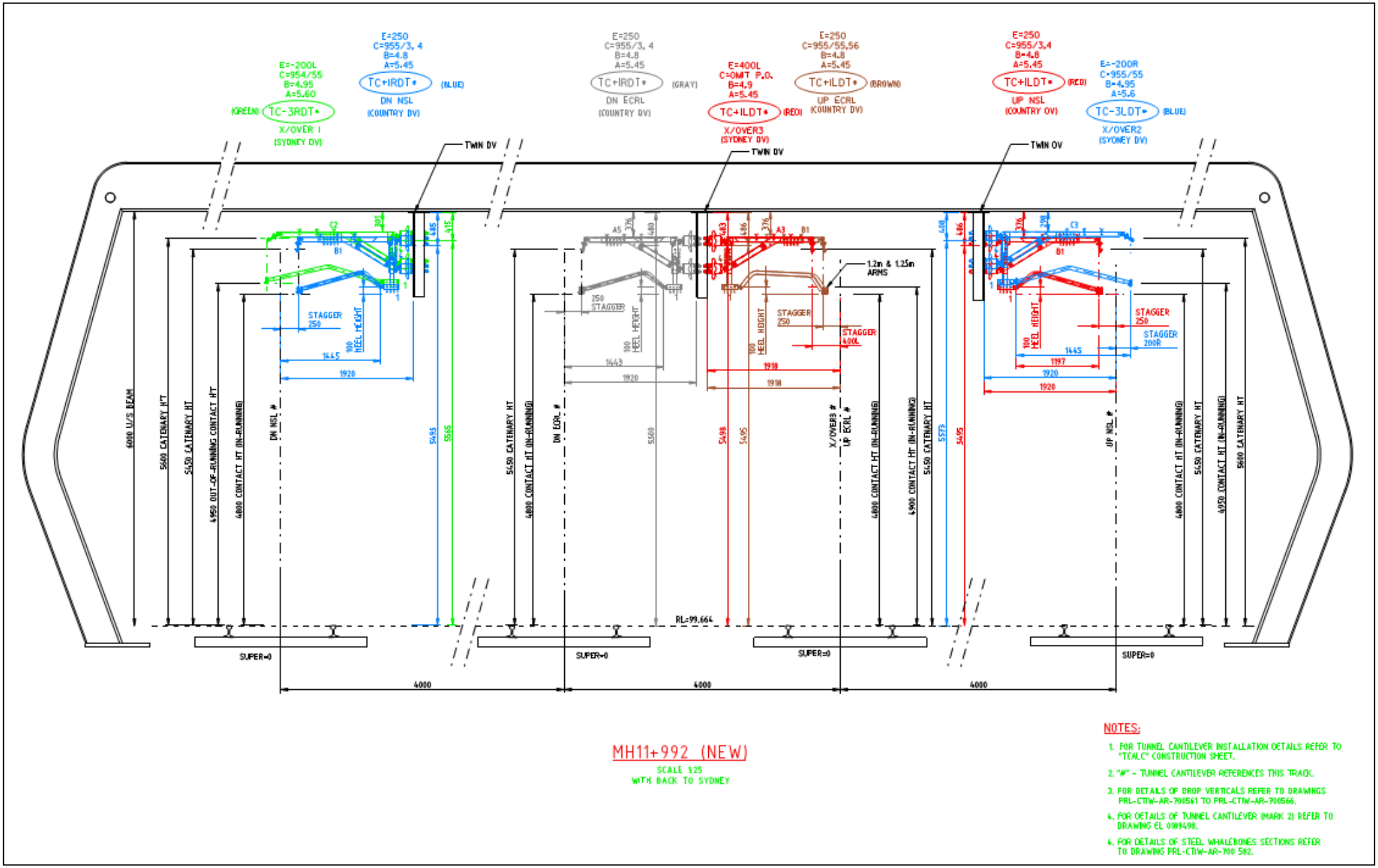
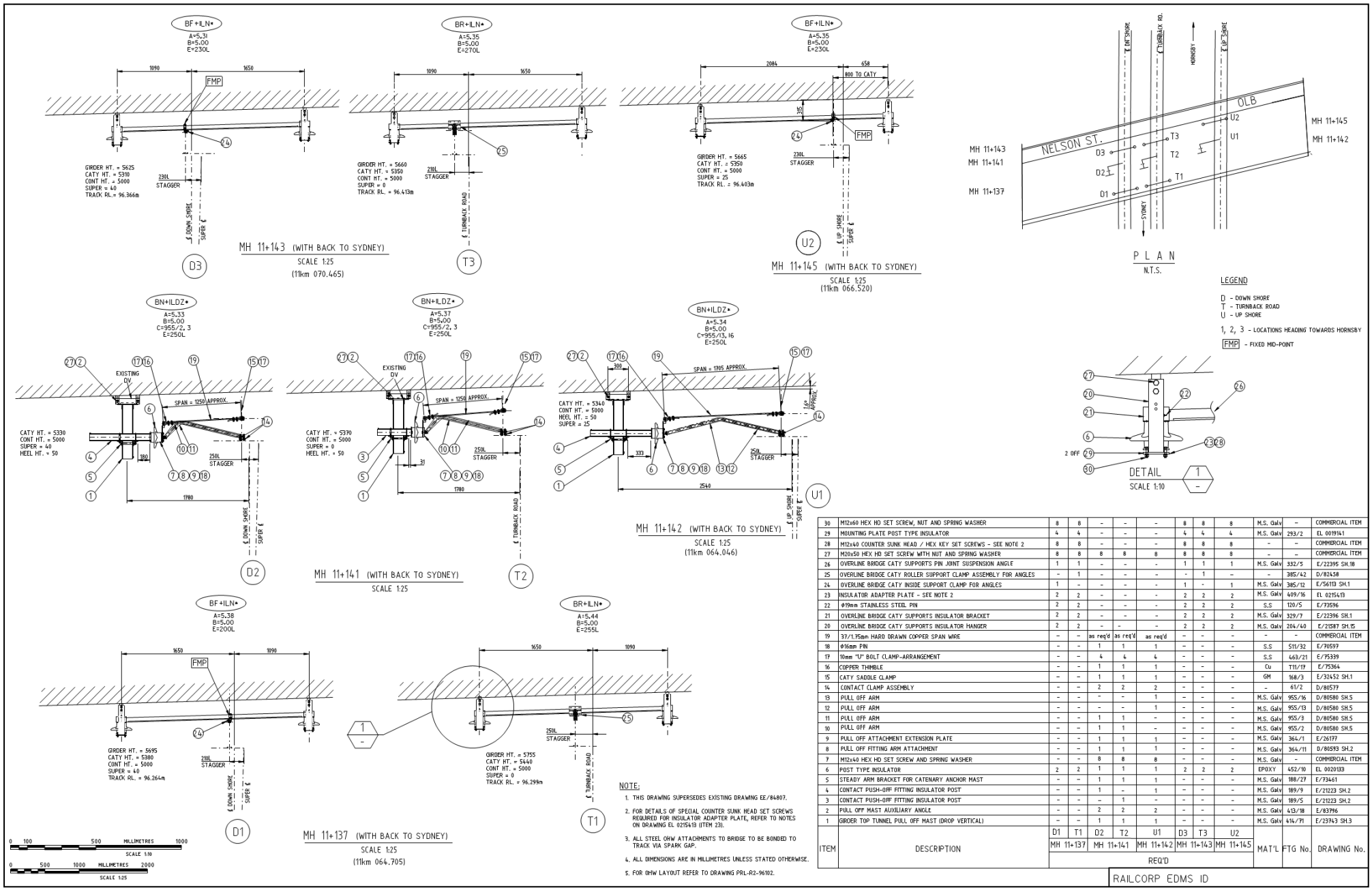


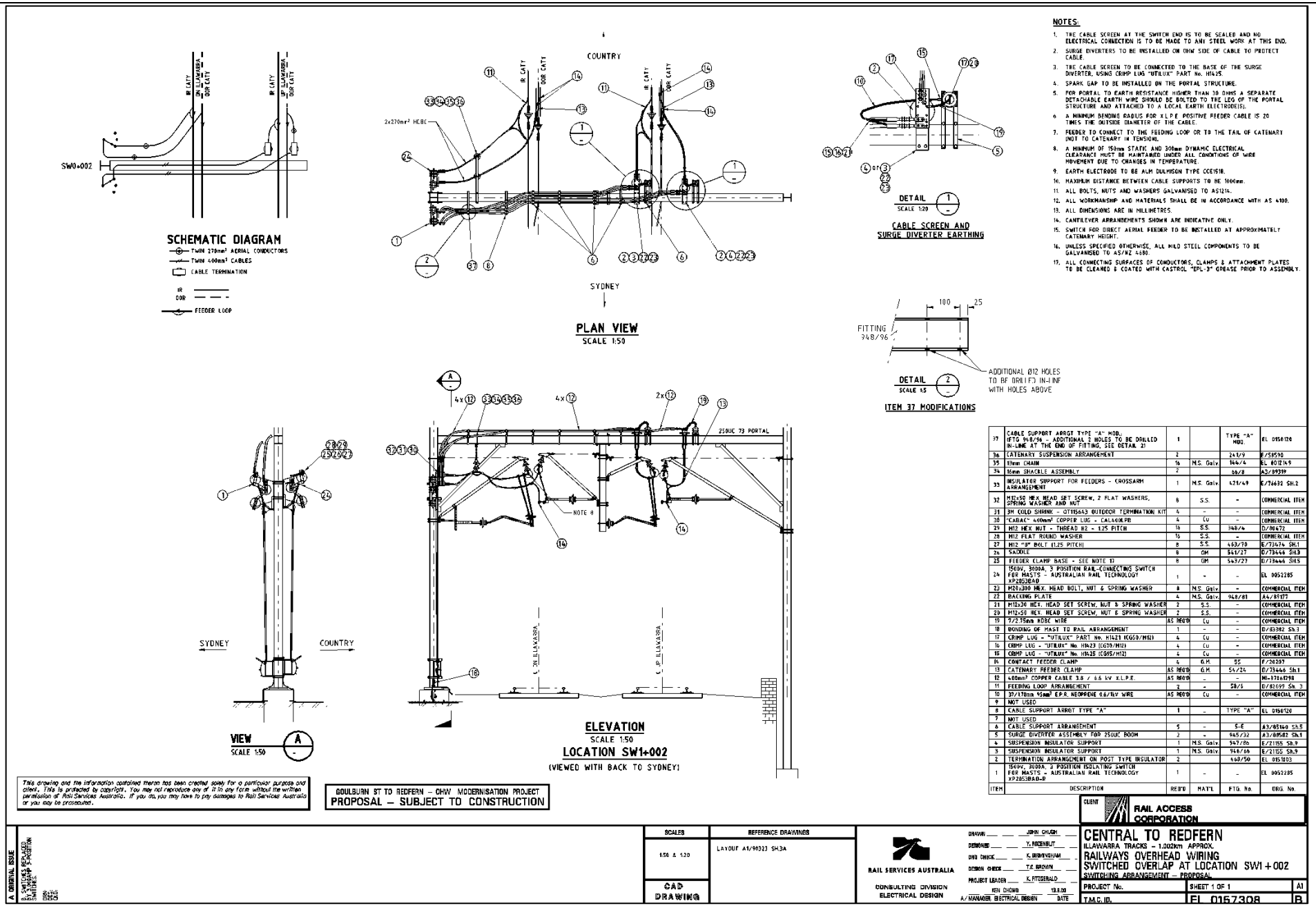
Figure 725 - Part-Copy of Typical Cross-Section (Chatswood)


MH 11+143 (WITH BACK TO SYDNEY)
SCALE 1:25
(11km 070.465)
MH 11+145 (WITH BACK TO SYDNEY)
SCALE 1:25
(11km 066.520)
P L A N
N.T.S.
NELSON ST.
OLB
MH 11+143
MH 11+141
MH 11+137
MH 11+145
MH 11+142
LEGEND
D - DOWN SHORE
T - TURNBACK ROAD
U - UP SHORE
1, 2, 3 - LOCATIONS HEADING TOWARDS HORNSBY
FMP - FIXED MID-POINT
DETAIL 1
SCALE 1:10
MH 11+142 (WITH BACK TO SYDNEY)
SCALE 1:25
(11km 064.046)
MH 11+141 (WITH BACK TO SYDNEY)
SCALE 1:25
MH 11+137 (WITH BACK TO SYDNEY)
SCALE 1:25
(11km 064.705)
NOTE:
1. THIS DRAWING SUPERSEDES EXISTING DRAWING EE/84807.
2. FOR DETAILS OF SPECIAL COUNTER SUNK HEAD SET SCREWS REQUIRED FOR INSULATOR ADAPTER PLATE, REFER TO NOTES ON DRAWING EL 0215413 (ITEM 23).
3. ALL STEEL OHW ATTACHMENTS TO BRIDGE TO BE BONDED TO TRACK VIA SPARK GAP.
4. ALL DIMENSIONS ARE IN MILLIMETRES UNLESS STATED OTHERWISE.
5. FOR OHW LAYOUT REFER TO DRAWING PRL-R2-96102.

ITEM	DESCRIPTION	D1 MH 11+137 REQ'D	T1 MH 11+141 REQ'D	D2 MH 11+142 REQ'D	T2 MH 11+142 REQ'D	U1 MH 11+142 REQ'D	D3 MH 11+143 REQ'D	T3 MH 11+143 REQ'D	U2 MH 11+145 REQ'D	MAT'L	FTG No.	DRAWING No.
30	M12x60 HEX HD SET SCREW, NUT AND SPRING WASHER	8	8	-	-	-	8	8	8	M.S. Galv	-	COMMERCIAL ITEM
29	MOUNTING PLATE POST TYPE INSULATOR	4	4	-	-	-	4	4	4	M.S. Galv	293/2	EL 0019141
28	M12x40 COUNTER SUNK HEAD / HEX KEY SET SCREWS - SEE NOTE 2	8	8	-	-	-	8	8	8	-	-	COMMERCIAL ITEM
27	M20x50 HEX HD SET SCREW WITH NUT AND SPRING WASHER	8	8	8	8	8	8	8	8	-	-	COMMERCIAL ITEM
26	OVERLINE BRIDGE CATY SUPPORTS PIN JOINT SUSPENSION ANGLE	1	1	-	-	-	1	1	1	M.S. Galv	332/5	E/22395 SH.18
25	OVERLINE BRIDGE CATY ROLLER SUPPORT CLAMP ASSEMBLY FOR ANGLES	-	1	-	-	-	-	1	-	-	385/42	D/82458
24	OVERLINE BRIDGE CATY INSIDE SUPPORT CLAMP FOR ANGLES	1	-	-	-	-	1	-	1	M.S. Galv	385/12	E/56113 SH.1
23	INSULATOR ADAPTER PLATE - SEE NOTE 2	2	2	-	-	-	2	2	2	M.S. Galv	409/16	EL 0215413
22	Φ19mm STAINLESS STEEL PIN	2	2	-	-	-	2	2	2	S.S	120/S	E/73596
21	OVERLINE BRIDGE CATY SUPPORTS INSULATOR BRACKET	2	2	-	-	-	2	2	2	M.S. Galv	329/7	E/22396 SH.1
20	OVERLINE BRIDGE CATY SUPPORTS INSULATOR HANGER	2	2	-	-	-	2	2	2	M.S. Galv	204/40	E/21587 SH.15
19	37/1.75mm HARD DRAWN COPPER SPAN WIRE	-	-	as req'd	as req'd	as req'd	-	-	-	-	-	COMMERCIAL ITEM
18	Φ16mm PIN	-	-	1	1	1	-	-	-	S.S	511/32	E/70597
17	10mm "U" BOLT CLAMP-ARRANGEMENT	-	-	4	4	4	-	-	-	S.S	463/21	E/75339
16	COPPER THIMBLE	-	-	1	1	1	-	-	-	Cu	T11/17	E/75364
15	CATY SADDLE CLAMP	-	-	1	1	1	-	-	-	GM	168/3	E/32452 SH.1
14	CONTACT CLAMP ASSEMBLY	-	-	2	2	2	-	-	-	-	61/2	D/80579
13	PULL OFF ARM	-	-	-	-	1	-	-	-	M.S. Galv	955/16	D/80580 SH.5
12	PULL OFF ARM	-	-	-	-	1	-	-	-	M.S. Galv	955/13	D/80580 SH.5
11	PULL OFF ARM	-	-	1	1	-	-	-	-	M.S. Galv	955/3	D/80580 SH.5
10	PULL OFF ARM	-	-	1	1	-	-	-	-	M.S. Galv	955/2	D/80580 SH.5
9	PULL OFF ATTACHMENT EXTENSION PLATE	-	-	1	1	1	-	-	-	M.S. Galv	364/1	E/26177
8	PULL OFF FITTING ARM ATTACHMENT	-	-	1	1	1	-	-	-	M.S. Galv	364/11	D/80593 SH.2
7	M12x40 HEX HD SET SCREW AND SPRING WASHER	-	-	8	8	8	-	-	-	M.S. Galv	-	COMMERCIAL ITEM
6	POST TYPE INSULATOR	2	2	1	1	1	2	2	2	EPOXY	452/10	EL 0020133
5	STEADY ARM BRACKET FOR CATENARY ANCHOR MAST	-	-	1	1	1	-	-	-	M.S. Galv	188/29	E/73461
4	CONTACT PUSH-OFF FITTING INSULATOR POST	-	-	1	-	1	-	-	-	M.S. Galv	189/9	E/21223 SH.2
3	CONTACT PUSH-OFF FITTING INSULATOR POST	-	-	-	1	-	-	-	-	M.S. Galv	189/5	E/21223 SH.2
2	PULL OFF MAST AUXILIARY ANGLE	-	-	2	2	2	-	-	-	M.S. Galv	413/18	E/83796
1	GIRDER TOP TUNNEL PULL OFF MAST (DROP VERTICAL)	-	-	1	1	1	-	-	-	M.S. Galv	414/71	E/23743 SH.3

RAILCORP EDMS ID

Figure 726 - Typical Bridge Arrangement Drawing (Chatswood)


SCHEMATIC DIAGRAM
PLAN VIEW
SCALE 1:50
ELEVATION
SCALE 1:50
LOCATION SW1+002
(VIEWED WITH BACK TO SYDNEY)
VIEW
SCALE 1:50
DETAIL
SCALE 1:20
CABLE SCREEN AND SURGE DIVERTER EARTHING
DETAIL
SCALE 1:5
ITEM 37 MODIFICATIONS
NOTES:
1. THE CABLE SCREEN AT THE SWITCH END IS TO BE SEALED AND NO ELECTRICAL CONNECTION IS TO BE MADE TO ANY STEEL WORK AT THIS END.
2. SURGE DIVERTERS TO BE INSTALLED ON OHW SIDE OF CABLE TO PROTECT CABLE.
3. THE CABLE SCREEN TO BE CONNECTED TO THE BASE OF THE SURGE DIVERTER, USING CRIMP LUG "UTILUX" PART No. H1425.
4. SPARK GAP TO BE INSTALLED ON THE PORTAL STRUCTURE.
5. FOR PORTAL TO EARTH RESISTANCE HIGHER THAN 30 OHMS A SEPARATE DETACHABLE EARTH WIRE SHOULD BE BOLTED TO THE LEG OF THE PORTAL STRUCTURE AND ATTACHED TO A LOCAL EARTH ELECTRODE(S).
6. A MINIMUM BENDING RADIUS FOR X.L.P.E. POSITIVE FEEDER CABLE IS 20 TIMES THE OUTSIDE DIAMETER OF THE CABLE.
7. FEEDER TO CONNECT TO THE FEEDING LOOP OR TO THE TAIL OF CATENARY (NOT TO CATENARY IN TENSION).
8. A MINIMUM OF 150mm STATIC AND 300mm DYNAMIC ELECTRICAL CLEARANCE MUST BE MAINTAINED UNDER ALL CONDITIONS OF WIRE MOVEMENT DUE TO CHANGES IN TEMPERATURE.
9. EARTH ELECTRODE TO BE ALM DULMISON TYPE CCE1518.
10. MAXIMUM DISTANCE BETWEEN CABLE SUPPORTS TO BE 1600mm.
11. ALL BOLTS, NUTS AND WASHERS GALVANISED TO AS1214.
12. ALL WORKMANSHIP AND MATERIALS SHALL BE IN ACCORDANCE WITH AS 4100.
13. ALL DIMENSIONS ARE IN MILLIMETRES.
14. CANTILEVER ARRANGEMENTS SHOWN ARE INDICATIVE ONLY.
15. SWITCH FOR DIRECT AERIAL FEEDER TO BE INSTALLED AT APPROXIMATELY CATENARY HEIGHT.
16. UNLESS SPECIFIED OTHERWISE, ALL MILD STEEL COMPONENTS TO BE GALVANISED TO AS/NZ 4680.
17. ALL CONNECTING SURFACES OF CONDUCTORS, CLAMPS & ATTACHMENT PLATES TO BE CLEANED & COATED WITH CASTROL "EPL-3" GREASE PRIOR TO ASSEMBLY.
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GOULBURN ST TO REDFERN – OHW MODERNISATION PROJECT
PROPOSAL – SUBJECT TO CONSTRUCTION
RAIL ACCESS CORPORATION
CENTRAL TO REDFERN
ILLAWARRA TRACKS – 1.00km APPROX.
RAILWAYS OVERHEAD WIRING
SWITCHED OVERLAP AT LOCATION SW1+002
SWITCHING ARRANGEMENT – PROPOSAL
RAIL SERVICES AUSTRALIA
CONSULTING DIVISION
ELECTRICAL DESIGN
SCALES
1:50 & 1:20
CAD DRAWING
REFERENCE DRAWINGS
LAYOUT A1/90323 SH3A
PROJECT No.
SHEET 1 OF 1
A1
T.M.C. ID.
EL 0157308
B

ITEM	DESCRIPTION	REQ'D	MAT'L	RTG. No.	DRG. No.
37	CABLE SUPPORT ARRGT TYPE "A" MOD. (RTG 96/94 – ADDITIONAL 3 HOLES TO BE DRILLED IN-LINE AT THE END OF FITTING, SEE DETAIL 2)	1		TYPE "A" MOD.	EL 0156120
36	CATENARY SUSPENSION ARRANGEMENT	2		241/9	E/58590
35	13mm CHAIN	16	M.S. Galv.	344/4	EL 60121.9
34	16mm SHACKLE ASSEMBLY	2		66/8	A3/89339
33	INSULATOR SUPPORT FOR FEEDERS – CROSSARM ARRANGEMENT	1	M.S. Galv.	421/49	E/76632 Sh.2
32	M12x50 HEX. HEAD SET SCREW, 2 FLAT WASHERS, SPRING WASHER AND NUT	8	S.S.	-	COMMERCIAL ITEM
31	3M COLD SHRINK – QT11643 OUTDOOR TERMINATION KIT	4	-	-	COMMERCIAL ITEM
30	"CABAC" 400mm² COPPER LUG – CALA40LFB	4	Cu	-	COMMERCIAL ITEM
29	M12 HEX NUT – THREAD H2 – 1.25 PITCH	16	S.S.	348/4	D/80472
28	M12 FLAT ROUND WASHER	16	S.S.	-	COMMERCIAL ITEM
27	M12 "U" BOLT (1.25 PITCH)	8	S.S.	453/19	E/73474 Sh.1
26	SADDLE	8	GM	561/27	D/73446 Sh3
25	FEEDER CLAMP BASE – SEE NOTE 17	8	GM	543/27	D/73446 Sh5
24	1500V, 3000A, 3 POSITION RAIL-CONNECTING SWITCH FOR MASTS – AUSTRALIAN RAIL TECHNOLOGY XP2053DA0	1	-	-	EL 0052285
23	M20x300 HEX. HEAD BOLT, NUT & SPRING WASHER	8	M.S. Galv.	-	COMMERCIAL ITEM
22	BACKING PLATE	4	M.S. Galv.	948/81	A4/85177
21	M12x30 HEX. HEAD SET SCREW, NUT & SPRING WASHER	2	S.S.	-	COMMERCIAL ITEM
20	M12x50 HEX. HEAD SET SCREW, NUT & SPRING WASHER	2	S.S.	-	COMMERCIAL ITEM
19	7/2.75mm ROBC WIRE	AS REQ'D	Cu	-	COMMERCIAL ITEM
18	BONDING OF MAST TO RAIL ARRANGEMENT	1	-	-	D/83382 Sh.3
17	CRIMP LUG – "UTILUX" PART No. H1421 (CG50/M12)	4	Cu	-	COMMERCIAL ITEM
16	CRIMP LUG – "UTILUX" No. H1423 (CG70/M12)	4	Cu	-	COMMERCIAL ITEM
15	CRIMP LUG – "UTILUX" No. H1425 (CG95/M12)	4	Cu	-	COMMERCIAL ITEM
14	CONTACT FEEDER CLAMP	4	G.M.	55	F/26397
13	CATENARY FEEDER CLAMP	AS REQ'D	G.M.	54/24	D/73446 Sh.1
12	400mm² COPPER CABLE 3.8 / 6.6 kV X.L.P.E.	AS REQ'D	-	-	MI-3786/298
11	FEEDING LOOP ARRANGEMENT	2	-	58/5	D/82699 Sh. 3
10	37/1.78mm 95mm² E.P.R. NEOPRENE 0.6/1kV WIRE	AS REQ'D	Cu	-	COMMERCIAL ITEM
9	NOT USED				
8	CABLE SUPPORT ARRGT TYPE "A"	1	-	TYPE "A"	EL 0156120
7	NOT USED				
6	CABLE SUPPORT ARRANGEMENT	5	-	5-E	A3/85140 Sh.5
5	SURGE DIVERTER ASSEMBLY FOR 250UC BOOM	2	-	945/32	A3/80582 Sh.1
4	SUSPENSION INSULATOR SUPPORT	1	M.S. Galv.	947/86	E/21155 Sh.9
3	SUSPENSION INSULATOR SUPPORT	1	M.S. Galv.	946/66	E/21155 Sh.9
2	TERMINATION ARRANGEMENT ON POST TYPE INSULATOR	2		460/50	EL 051103
1	1500V, 3000A, 2 POSITION ISOLATING SWITCH FOR MASTS – AUSTRALIAN RAIL TECHNOLOGY XP2053BAD-P	1	-	-	EL 0052285

Figure 727 - Typical Switch Arrangement Drawing (at Central)

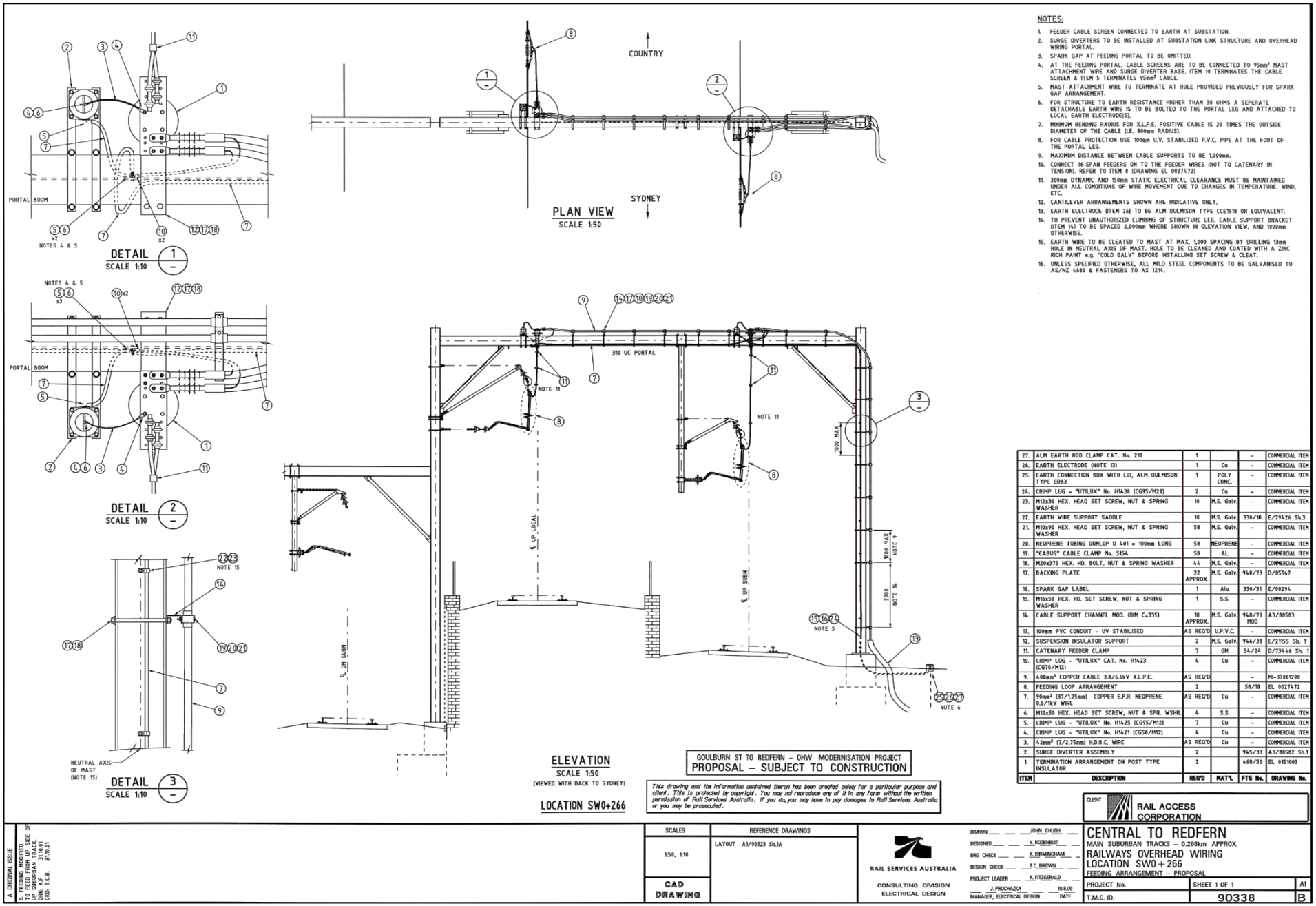

NOTES:
1. FEEDER CABLE SCREEN CONNECTED TO EARTH AT SUBSTATION.
2. SURGE DIVERTERS TO BE INSTALLED AT SUBSTATION LINK STRUCTURE AND OVERHEAD WIRING PORTAL.
3. SPARK GAP AT FEEDING PORTAL TO BE OMITTED.
4. AT THE FEEDING PORTAL, CABLE SCREENS ARE TO BE CONNECTED TO 95mm² MAST ATTACHMENT WIRE AND SURGE DIVERTER BASE. ITEM 10 TERMINATES THE CABLE SCREEN & ITEM 5 TERMINATES 95mm² CABLE.
5. MAST ATTACHMENT WIRE TO TERMINATE AT HOLE PROVIDED PREVIOUSLY FOR SPARK GAP ARRANGEMENT.
6. FOR STRUCTURE TO EARTH RESISTANCE HIGHER THAN 30 OHMS A SEPERATE DETACHABLE EARTH WIRE IS TO BE BOLTED TO THE PORTAL LEG AND ATTACHED TO LOCAL EARTH ELECTRODE(S).
7. MINIMUM BENDING RADIUS FOR X.L.P.E. POSITIVE CABLE IS 20 TIMES THE OUTSIDE DIAMETER OF THE CABLE (I.E. 800mm RADIUS).
8. FOR CABLE PROTECTION USE 100mm U.V. STABILIZED P.V.C. PIPE AT THE FOOT OF THE PORTAL LEG.
9. MAXIMUM DISTANCE BETWEEN CABLE SUPPORTS TO BE 1,000mm.
10. CONNECT IN-SPAN FEEDERS ON TO THE FEEDER WIRES (NOT TO CATENARY IN TENSION). REFER TO ITEM 9 (DRAWING EL 0027472)
11. 300mm DYNAMIC AND 150mm STATIC ELECTRICAL CLEARANCE MUST BE MAINTAINED UNDER ALL CONDITIONS OF WIRE MOVEMENT DUE TO CHANGES IN TEMPERATURE, WIND, ETC.
12. CANTILEVER ARRANGEMENTS SHOWN ARE INDICATIVE ONLY.
13. EARTH ELECTRODE (ITEM 26) TO BE ALM DULMISON TYPE CCE1518 OR EQUIVALENT.
14. TO PREVENT UNAUTHORIZED CLIMBING OF STRUCTURE LEG, CABLE SUPPORT BRACKET (ITEM 14) TO BE SPACED 2,000mm WHERE SHOWN IN ELEVATION VIEW, AND 1000mm OTHERWISE.
15. EARTH WIRE TO BE CLEATED TO MAST AT MAX. 1,000 SPACING BY DRILLING 13mm HOLE IN NEUTRAL AXIS OF MAST. HOLE TO BE CLEANED AND COATED WITH A ZINC RICH PAINT e.g. "COLD GALV" BEFORE INSTALLING SET SCREW & CLEAT.
16. UNLESS SPECIFIED OTHERWISE, ALL MILD STEEL COMPONENTS TO BE GALVANISED TO AS/NZ 4680 & FASTENERS TO AS 1214.
PLAN VIEW
SCALE 1:50
COUNTRY
SYDNEY
DETAIL 1
SCALE 1:10
PORTAL BOOM
NOTES 4 & 5
DETAIL 2
SCALE 1:10
DETAIL 3
SCALE 1:10
NEUTRAL AXIS OF MAST (NOTE 15)
ELEVATION
SCALE 1:50
(VIEWED WITH BACK TO SYDNEY)
LOCATION SW0+266
310 UC PORTAL
NOTE 11
NOTE 5
NOTE 6
1000 MAX
2000
GOULBURN ST TO REDFERN – OHW MODERNISATION PROJECT
PROPOSAL – SUBJECT TO CONSTRUCTION
This drawing and the information contained therein has been created solely for a particular purpose and client. This is protected by copyright. You may not reproduce any of it in any form without the written permission of Rail Services Australia. If you do, you may have to pay damages to Rail Services Australia or you may be prosecuted.
27. ALM EARTH ROD CLAMP CAT. No. 210 — 1 — – — COMMERCIAL ITEM
26. EARTH ELECTRODE (NOTE 13) — 1 — Cu — – — COMMERCIAL ITEM
25. EARTH CONNECTION BOX WITH LID, ALM DULMISON TYPE ERB3 — 1 — POLY CONC. — – — COMMERCIAL ITEM
24. CRIMP LUG – "UTILUX" No. H1438 (CG95/M20) — 2 — Cu — – — COMMERCIAL ITEM
23. M12x30 HEX. HEAD SET SCREW, NUT & SPRING WASHER — 10 — M.S. Galv. — – — COMMERCIAL ITEM
22. EARTH WIRE SUPPORT SADDLE — 10 — M.S. Galv. — 330/18 — E/79426 Sh.3
21. M10x90 HEX. HEAD SET SCREW, NUT & SPRING WASHER — 58 — M.S. Galv. — – — COMMERCIAL ITEM
20. NEOPRENE TUBING DUNLOP D 401 = 100mm LONG — 58 — NEOPRENE — – — COMMERCIAL ITEM
19. "CABUS" CABLE CLAMP No. 5154 — 58 — AL — – — COMMERCIAL ITEM
18. M20x375 HEX. HD. BOLT, NUT & SPRING WASHER — 44 — M.S. Galv. — – — COMMERCIAL ITEM
17. BACKING PLATE — 22 APPROX. — M.S. Galv. — 948/73 — D/85967
16. SPARK GAP LABEL — 1 — Alu — 330/31 — E/88294
15. M16x50 HEX. HD. SET SCREW, NUT & SPRING WASHER — 1 — S.S. — – — COMMERCIAL ITEM
14. CABLE SUPPORT CHANNEL MOD. (DIM C=335) — 18 APPROX. — M.S. Galv. — 948/79 MOD — A3/88583
13. 100mm PVC CONDUIT – UV STABILISED — AS REQ'D — U.P.V.C. — – — COMMERCIAL ITEM
12. SUSPENSION INSULATOR SUPPORT — 2 — M.S. Galv. — 944/38 — E/21155 Sh. 9
11. CATENARY FEEDER CLAMP — 7 — GM — 54/24 — D/73446 Sh. 1
10. CRIMP LUG – "UTILUX" CAT. No. H1423 (CG70/M12) — 4 — Cu — – — COMMERCIAL ITEM
9. 400mm² COPPER CABLE 3.8/6.6kV X.L.P.E. — AS REQ'D — — — MI-37061298
8. FEEDING LOOP ARRANGEMENT — 2 — — 58/10 — EL 0027472
7. 90mm² (37/1.75mm) COPPER E.P.R. NEOPRENE 0.6/1kV WIRE — AS REQ'D — Cu — – — COMMERCIAL ITEM
6. M12x50 HEX. HEAD SET SCREW, NUT & SPR. WSHR. — 4 — S.S. — – — COMMERCIAL ITEM
5. CRIMP LUG – "UTILUX" No. H1425 (CG95/M12) — 7 — Cu — – — COMMERCIAL ITEM
4. CRIMP LUG – "UTILUX" No. H1421 (CG50/M12) — 4 — Cu — – — COMMERCIAL ITEM
3. 42mm² (7/2.75mm) H.D.B.C. WIRE — AS REQ'D — Cu — – — COMMERCIAL ITEM
2. SURGE DIVERTER ASSEMBLY — 2 — — 945/33 — A3/88582 Sh.1
1. TERMINATION ARRANGEMENT ON POST TYPE INSULATOR — 2 — — 468/50 — EL 0151003
ITEM | DESCRIPTION | REQ'D | MAT'L | FTG No. | DRAWING No.
A ORIGINAL ISSUE
B FEEDING MODIFIED TO SUIT NEW SUB UP SUBURBAN TRACK. DRN: K.F. CHD: T.C.B. 31.10.01
SCALES
1:50, 1:10
CAD DRAWING
REFERENCE DRAWINGS
LAYOUT A1/90323 Sh.1A
RAIL SERVICES AUSTRALIA
CONSULTING DIVISION
ELECTRICAL DESIGN
DRAWN JOHN CHUGH
DESIGNED Y. ROZENBUT
DRG CHECK K. BIRMINGHAM
DESIGN CHECK T.C. BROWN
PROJECT LEADER K. FITZGERALD
J. PROCHAZKA 16.8.00
MANAGER, ELECTRICAL DESIGN DATE
CLIENT
RAIL ACCESS CORPORATION
CENTRAL TO REDFERN
MAIN SUBURBAN TRACKS – 0.266km APPROX.
RAILWAYS OVERHEAD WIRING
LOCATION SW0+266
FEEDING ARRANGEMENT – PROPOSAL
PROJECT No. 90338
SHEET 1 OF 1
A1
T.M.C. ID.
B

Figure 728 - Typical Feeding Arrangement Drawing (at Central)

10.2 APPENDIX "B" – SWITCHING & FEEDING SITUATIONS

The following pages show examples of typical OHW switching and feeding situations and configurations.

They may not be exhaustive and they may not show the current policy, especially in terms of earthing and bonding. For example, the decision whether or not to spark gap a structure can be a point of conjecture, since spark gaps take away risk from one area but can add it to another.

Please note that policies on earthing and bonding configurations can change at any time, so *need to consult the current policy/standard before designing any arrangement*.

The diagrams are meant for reference only, to help understand and consider the various ways OHW can be switched and/or fed from a substation or sectioning hut.

The design of such site-specific arrangements should be coordinated with, and signed-off by, experts in earthing and bonding in Sydney's dc OHW system.

Finally, it is not intended to deal with what goes on inside a substation or sectioning hut, as this area is outside the scope of this document. It's what happens to the feeding of OHW that is the focus here, and the electrical requirements and mechanical arrangement of items to feed the OHW are the domain of an OHW Design Engineer.

The various scenarios which follow are:

A. Aerial Feed from Substation or Sectioning Hut (3 situations)
B. Aerial Feed from Stand-Alone Switch (2 situations)
C. Cable Feed from Substation (3 situations)
D. Cable Feed from Sectioning Hut (3 situations)
E. Cable Feed from Stand-Alone Switch (2 situations)

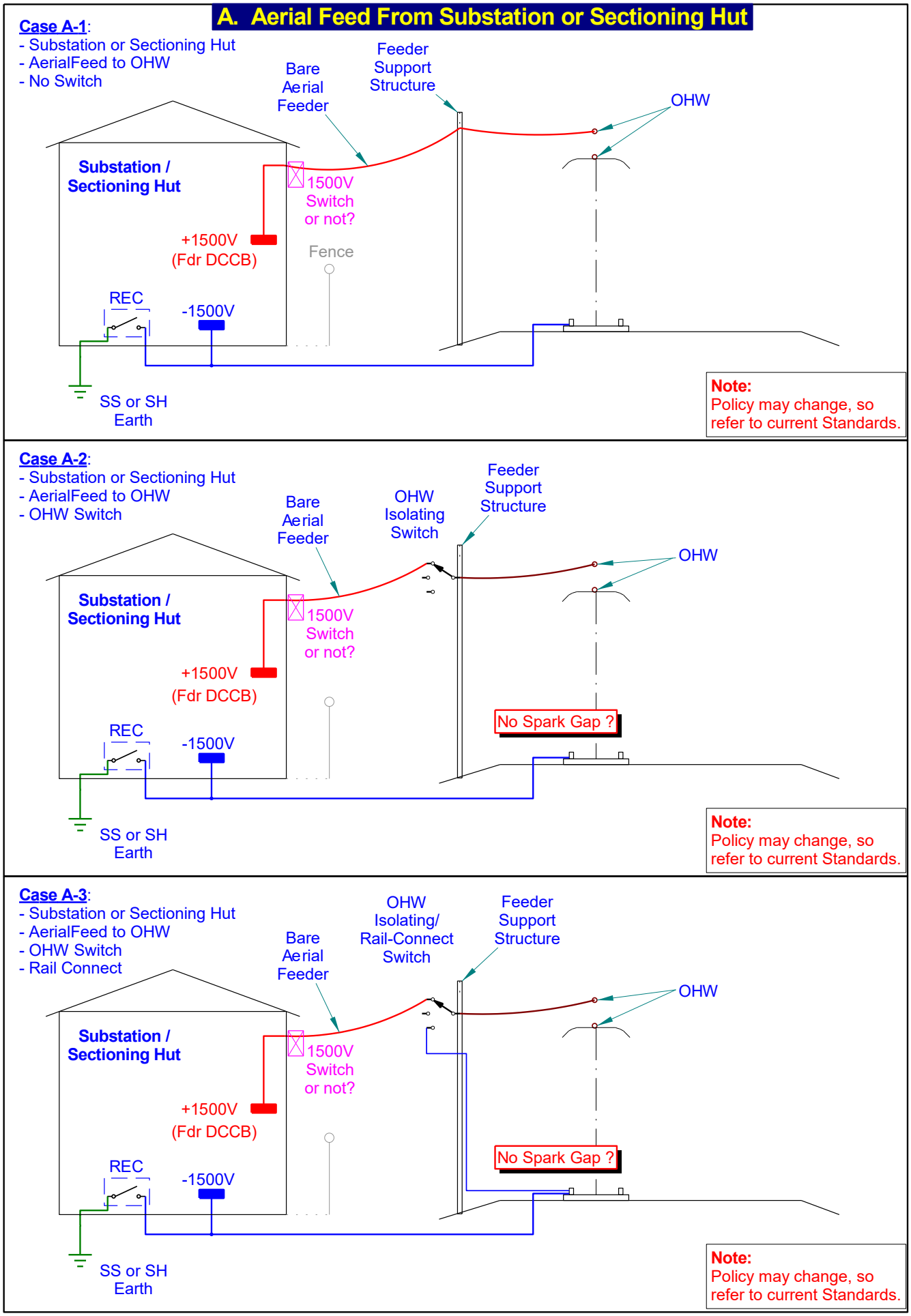


Figure 729 - Case "A" - Aerial Feed from Substation or Sectioning Hut

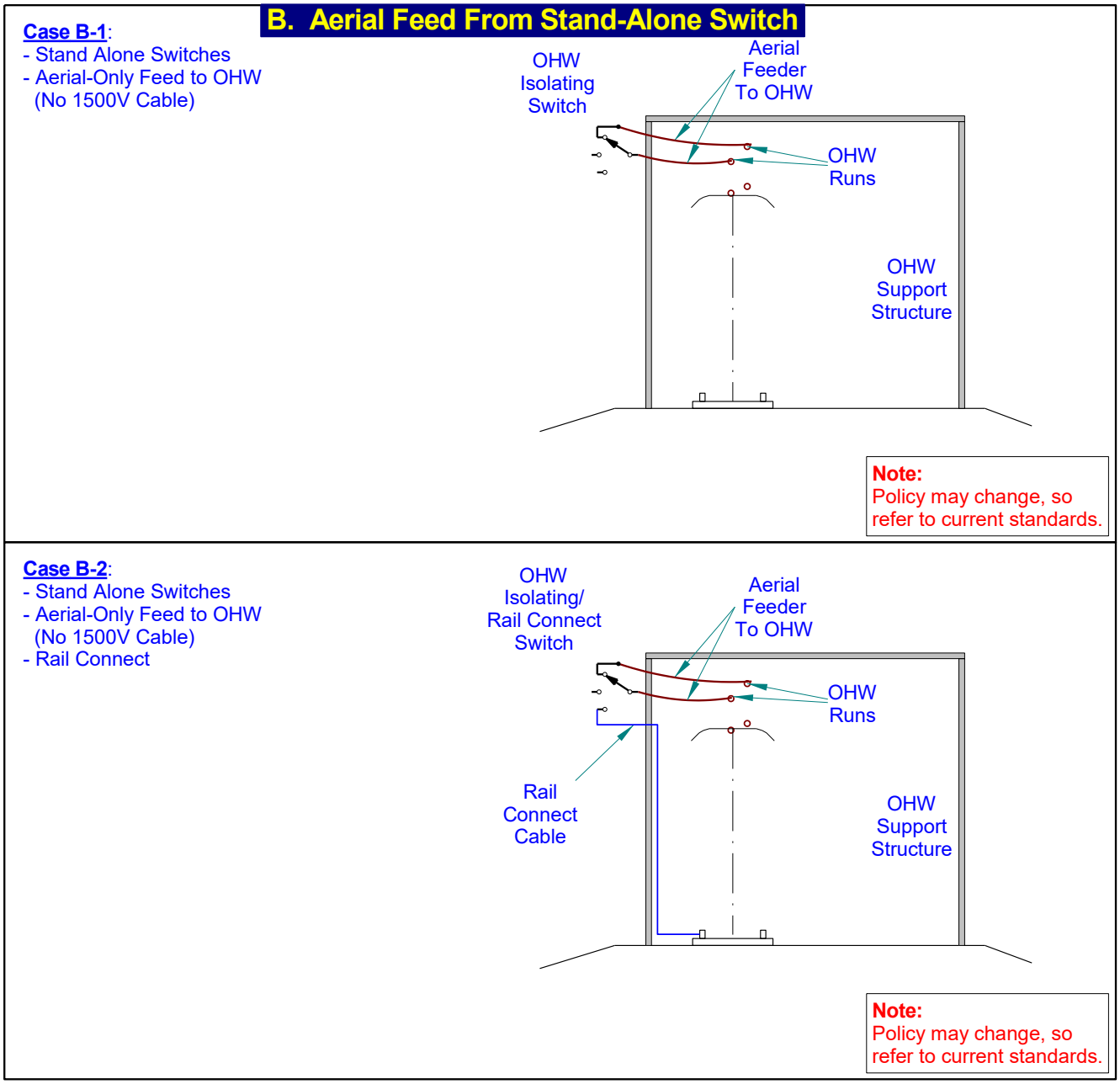


Figure 730 - Case "B" - Aerial Feed from Stand-Alone Switch

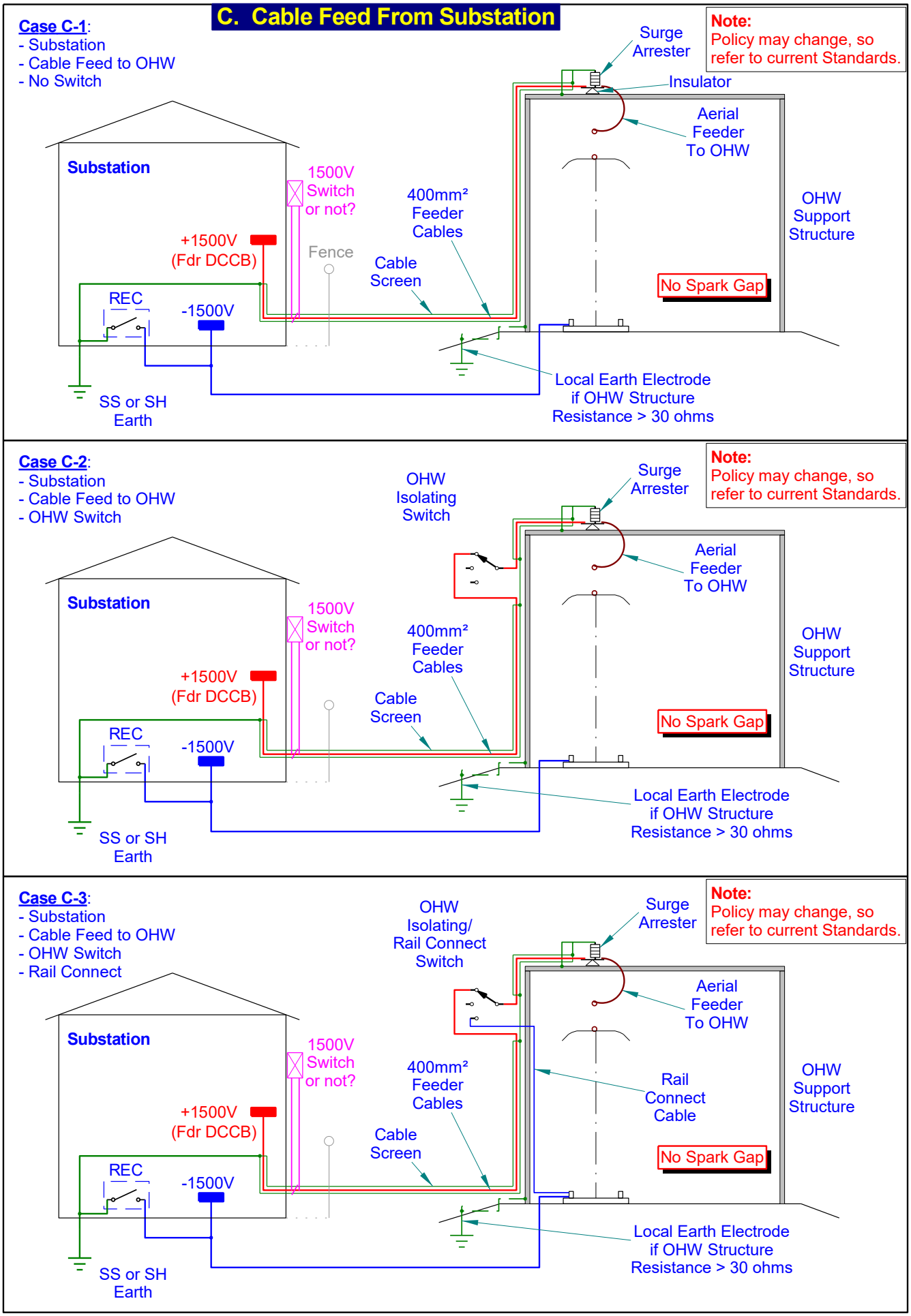


Figure 731 - Case "C" - Cable Feed from Substation

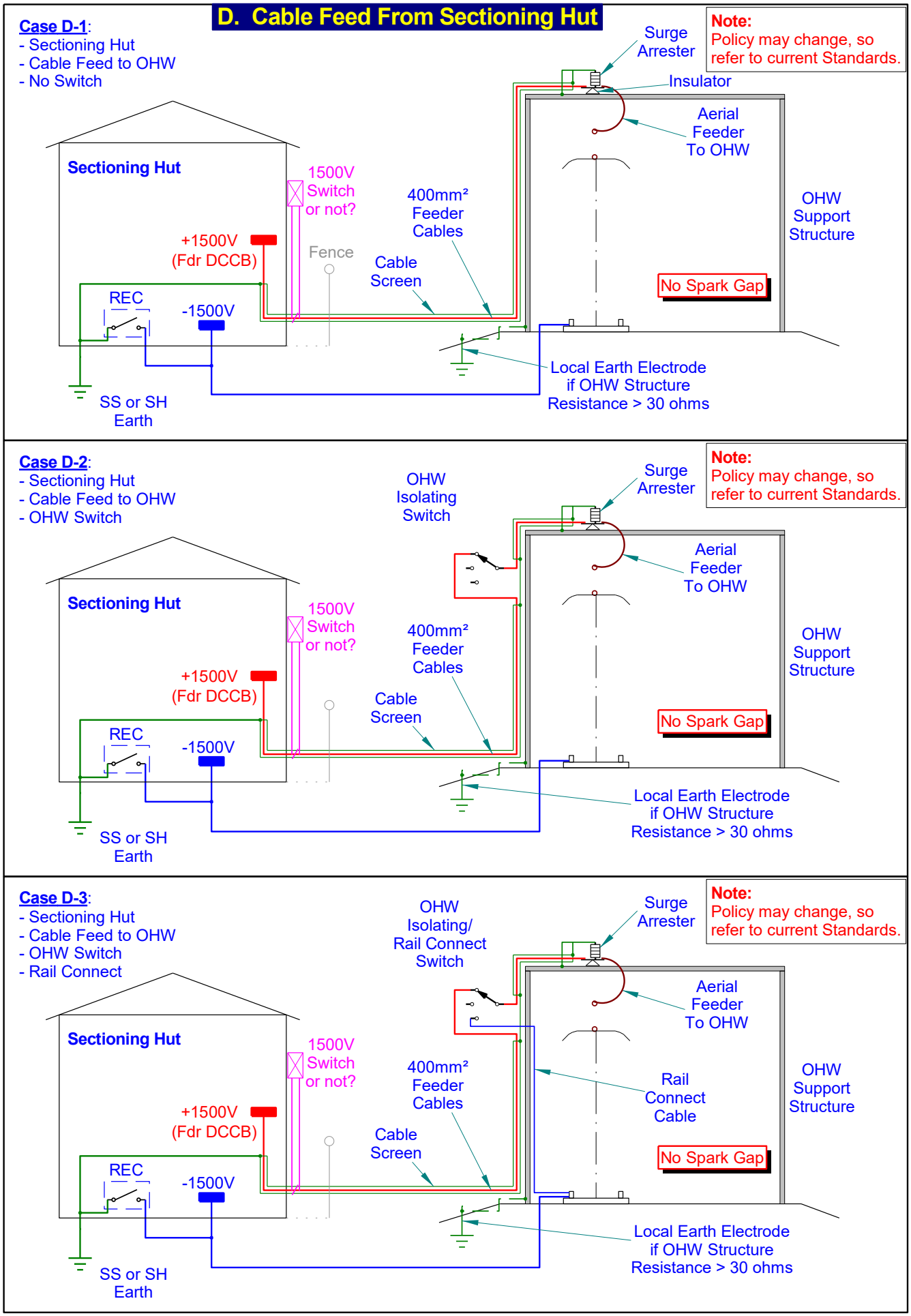


Figure 732 - Case "D" - Cable Feed from Sectioning Hut

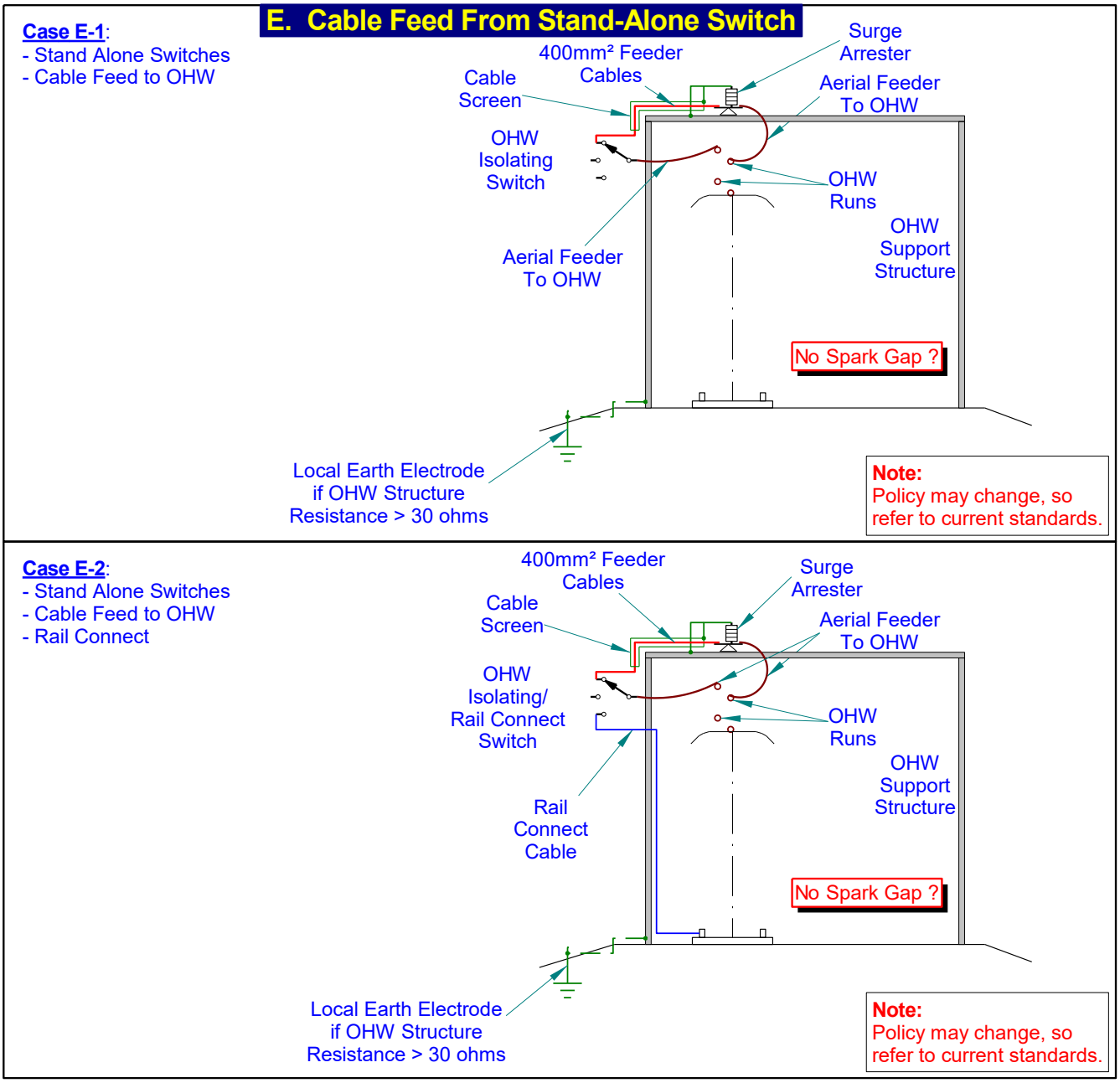


Figure 733 - Case "E" - Cable Feed from Stand-Alone Switch

10.3 APPENDIX "C" – PANTOGRAPH SECURITY

The Pantograph Security document shown below in *Figure 734* and *Figure 735* is an extremely important document for Sydney's electric train system. It was based on an industry presentation given by A/Supervising Engineer, F.C.P. (Phil) Smythe, entitled "*Overhead Wiring Design for Pantograph Security*".

This area is important because it budgets how much of the lateral space on the top flat length of the pantograph head is apportioned to the below 3 entities (with their corresponding tolerances).

This is needed to ensure that the contact wire can never be in a position to lose control of the upward force of the pantograph itself – a term called "*Pantograph Security*". If it does lose control, then this will wreak much damage to the pantograph/s and the interfacing overhead wiring, until the train comes to rest (which may take many hundreds of metres). The consequent damage can be immense and take a long time to repair, disrupting train services in the meanwhile.

In other words, without this policy / agreement, the ability of the OHW to reliably deliver electric power to trains would be severely jeopardised.

There are 3 independent entities in this train supply situation:

- The *Track* (that the train runs along).
- The *Pantograph* on top of the train (there can be several pantographs on each train consist).
- The *Contact Wire* (controlling the pantograph's height, and transmitting electric power to and from the train via the pantograph).

This budgeting can help to determine the cause of a pantograph incident (should one occur). The investigation of incidents can otherwise be a time-consuming task, and lead to uncertain outcomes.

For more information, refer to *Section 6.3.2.2*, *Pantograph Security*. It includes a diagram that summarises the outcome – *Figure 691*.

PANTOGRAPH SECURITY

THE SECURITY OF THE PANTOGRAPH IS DETERMINED BY THE MAXIMUM DYNAMIC DISPLACEMENT OF THE CONTACT WIRE FROM THE PANTOGRAPH CENTRELINE
THE CONTACT WIRE DESIGN MUST ACCOUNT FOR PANTOGRAPH MOVEMENT DUE TO VEHICLE OSCILLATION AND TRACK TOLERANCES AND FOR THE DYNAMIC WIRE DISPLACEMENT DUE TO BLOW OUT FROM THE DESIGN SUPERELEVATED TRACK CENTRELINE.

A. TENSION LENGTH > 700m
THIS CONDITION IS USUALLY ASSOCIATED WITH TANGENT TRACK OR LARGE RADIUS CURVES BAYS ARE NORMALLY > 50m. BECAUSE BLOWOUT IS SIGNIFICANT IN LONG BAYS AND THE EFFECT OF STAGGER MOVEMENT DUE TO CANTILEVER SWING IS APPRECIABLE, THE STAGGER IS SET AT 250mm AT THE SUPPORT STRUCTURES THIS SETS THE MID BAY STAGGER + BLOWOUT TO < 350mm

B. TENSION LENGTH <700m
THIS CONDITION IS USUALLY ASSOCIATED WITH SMALL RADIUS CURVES AND BAYS OF < 50m
THE MAIN DANGER TO PANTOGRAPH SECURITY IN THIS SITUATION IS VEHICLE DYNAMICS AND TRACK TOLERANCE AT MID BAY
TO ENSURE THAT THE CONTACT REMAINS ON THE PANTOGRAPH UNDER THE WORST CONDITIONS THE WIRE IS STAGGERED 300mm AT SUPPORT STRUCTURES THIS REDUCES THE MID BAY STAGGER, THUS LIMITING THE VALUE OF MID BAY STAGGER + BLOWOUT TO 300mm

FOR RADII > 2000m STAGGERS ARE ADJUSTED TO APPROXIMATE THE VERSINE (MID BAY STAGGER CRITERIA.)

THE THEORETICAL STRUCTURE SPACING IS DETERMINED FROM

$$L = \sqrt{\frac{600}{\frac{125}{R} + \frac{0.0046 D_2 V^2 \times K}{T_2}}}$$

CRITERIA	STAGGER AT REGISTRATION	MID BAY STAGGER + BLOWOUT
TENSION LENGTHS > 700m OR BAY LENGTHS > 50 m	250 mm	350mm MAX
TENSION LENGTHS < 700m OR BAY LENGTHS < 50 m	300mm	300mm MAX

THE STRUCTURE SPACING SHOWN IN COLUMN 2 OF DRG D/86854 SHEETS 3,4,5 & 6 IS DETERMINED FROM THE INTEGER VALUE OF THE EQUATION REDUCED BY ONE METRE TO ALLOW FOR MAST REPLACEMENT AND FIELD ERECTION TOLERANCES.

THE NUMERATOR 600 = STAGGER AT REGISTRATION + MID BAY STAGGER + BLOWOUT (SEE TABLE ABOVE)

EL0006421

A ORIGINAL ISSUE
1W DES NEWCASTLE
1W DES LAWSON
3W NS, SW DO
3W CONST
MICROFILM
B Last line of Title NGS T/Wire 550 m, Data Sheet, DRN 2.M CKD KF 6/9/82

STATE RAIL AUTHORITY OF N.S.W.
ELECTRICAL BRANCH
RAILWAYS OVERHEAD WIRING
MARK 2 CANTILEVER CONSTRUCTION
PANTOGRAPH SECURITY DESCRIPTION

Passed KF
Drn GB
Tcd AH
Ckd GB
Scale —

APPROVED J Murchin A/MANAGER DESIGN 11.1.88

D 86854 SH No. 1
A B

Figure 734 - Pantograph Security Description Document – Page 1 of 2

KEY

D_1	=	CATENARY DIAMETER	MILLIMETRES
D_2	=	CONTACT DIAMETER	MILLIMETRES
T_1	=	CATENARY TENSION	NEWTONS
T_2	=	CONTACT TENSION	NEWTONS
V	=	WIND VELOCITY	Km/h
R	=	RADIUS OF CURVE	METRES
L	=	STRUCTURE SPACING	METRES
B/O	=	BLOWOUT	MILLIMETRES
VS	=	VERSINE	MILLIMETRES
RL	=	RADIAL LOAD	NEWTONS
WL	=	WIND LOAD	NEWTONS
AC	=	ADVERSE CONDITION	NEWTONS
MBS	=	MID BAY STAGGER	MILLIMETRES
WtL	=	WEIGHT LOAD	NEWTONS
W	=	SYSTEM WEIGHT/METRE	NEWTON/METRE
WS	=	WIND SPAN	METRES
WtS	=	WEIGHT SPAN	METRES

MAX CONTACT WIRE DISPLACEMENT AT MID BAY = MEAN STAGGER - VERSINE ± BLOWOUT

$$\text{MEAN STAGGER} = \text{STAGGERS } \frac{A+B}{2}$$

$$\text{MBS} = \text{VS} - \text{MEAN STAGGER}$$

$$\text{VS} = \frac{125 \times L^2}{R}$$

$$\text{RL} = \frac{T \times WS}{R}$$

$$\text{B/O} = \frac{0{\cdot}0046\ D_2 V^2\ WS^2 \times K}{T_2}$$

WHERE K=1 FOR SINGLE CONTACT
AND K=0·9 FOR TWIN CONTACT

CATY STATIC WL = $(3\,693 \times 10^{-5} \times D_1 \times V^2 \times L) + 25\%$

CATY DYNAMIC WL = CATY STATIC WL + 50 %

CONT STATIC WL = $3{\cdot}693 \times 10^{-5} \times D_2 \times V^2 \times L$

CONT DYNAMIC WL = CONT STATIC WL + 50 %

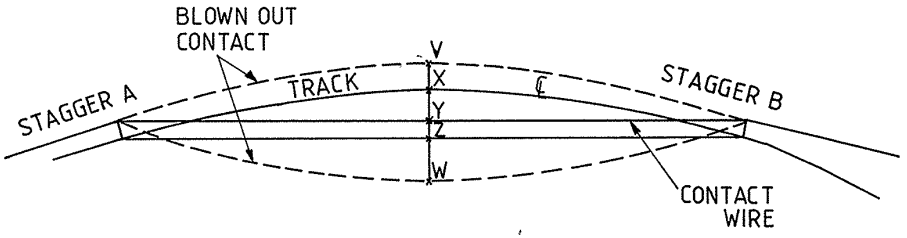
NOTE: TWIN CONTACT WIND LOAD =1·8× SINGLE LOAD

WIND VELOCITY = 130 Km/h

AC = RL - WL (DYNAMIC)

STATIC WtL = WtS × W

DYNAMIC WtL = STATIC + (50% OR 1067N) WHICH EVER IS GREATER



XZ = VERSINE YV = +Ve BLOWOUT
YZ = MEAN STAGGER YW = -Ve BLOWOUT
XY = MID BAY STAGGER

EL0006422

A Original Issue
IW DES. NEWCASTLE
IW DES. LANSDOWNE
IW MTS. SW 20
IW CONSTR. MACARTHUR
B Last line of title was n/l/w=550mm, data sheet, DRN ZN CKD KF 6/3/20

STATE RAIL AUTHORITY OF N.S.W
ELECTRICAL BRANCH
RAILWAYS OVERHEAD WIRING
MARK 2 CANTILEVER CONSTRUCTION
PANTOGRAPH SECURITY DESCRIPTION

Passed KF
Drn JRB
Tcd RA
Ckd JB
Scale —
APPROVED Minchin 11.1 88 MANAGER DESIGN
D 86854 Sh No 2
A B

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